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NWC TP 4361

AN/FPS-102 SYSTEM
PILOT TRAINING RANGES

by

Everett B. Hill and Ronald D. Hise
Aviation Ordnance Department

ABSTRACT. This report describes in detail the instrumentation necessary for training aircraft pilots in bombing techniques. The essential elements of the system are a modified M-33 radar, two Model 5 optical trackers, two Model 5 flight-profile plotters, six skyscreens, three impact-spotting quadrants, one impact-spotting board, and a timing console. When the training includes dive bombing and conventional-weapons delivery, optical acquisition and radar acquisition systems are added. This equipment measures the aircraft's speed and flight path while it performs these maneuvers.

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CHINA LAKE, CALIFORNIA ✱ FEBRUARY 1969

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M. R. Etheridge, Capt., USN .... Commander
Thomas S. Amlie, Ph.D. .... Technical Director

FOREWORD

One of the specialized missions of the aircraft range complex at the Naval Weapons Center (NWC), China Lake, California, is the support of the Fleet and the Operational Test and Evaluation Force in the development of training techniques and instrumentation for conventional- and special-weapons delivery. This report describes the range instrumentation developed for pilot training in the delivery of these weapons. For additional information on this type of range, refer to Model 5 Tracker and Profile Plotter, Skyscreen Telescope and Associated Electrical Equipment—Description, Operation and Maintenance, A Preliminary Manual (NOTS TP 3330).

This project is of a continuing nature and has been conducted under Local Project 256.

This report has been reviewed for technical accuracy by R. M. McClung.

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INTRODUCTION

This report discusses the present state of instrumentation for training pilots in both special-weapons delivery techniques and conventional-weapons delivery as developed at the Naval Weapons Center.

The information herein informs the range officer of the basic requirements for range construction in terms of both real estate and instrumentation. Instrumentation and data-receiving capabilities are described to inform range personnel and the squadrons using the range. Pilots trained on these ranges are better-trained and qualify in one-fourth the training time required for uninstrumented ranges.

The range instrumentation was first developed to provide pilots with plotted data on delivery of high-yield weapons. High-speed, low-level delivery tactics are necessary to enable the pilot to penetrate enemy radar defenses when manned aircraft are used in delivering high-yield weapons, but weapons delivered in this manner render the pilot and plane vulnerable to the resultant blast due to the relatively short time of fall. For this reason, it was necessary to develop a tactic by which the time of fall could be increased without using parachutes or retarding devices on the weapons. Both loft and over-the-shoulder deliveries were investigated. It was determined that, by using these maneuvers, an acceptable degree of delivery accuracy could be achieved with sufficient time of fall to permit the pilot and plane to escape blast damage.

Pilot training ranges must be developed whenever new weapons-delivery techniques are evolved. At NWC, the following instrumentation was developed: (1) the skyscreen system to measure airspeed during run-in, (2) an auxiliary tracker speed-switch system to use when adverse weather conditions render the skyscreen system ineffectual, and (3) the mechanical profile plotter for plotting the contour of the aircraft's flight path in the vertical plane over the flight line and the deviation of the aircraft from this plane during run-in, pull-up, and escape—a prerequisite for the correction of errors. (The plotter is driven by signals received from a modified M-33 radar that enables it to plot the position of the aircraft in range, horizontal distance, and elevation. Figure 1 shows the flight path of an aircraft doing special-weapons delivery. The path is identical in both loft and over-the-shoulder delivery, except that the pull-up and release points are changed.

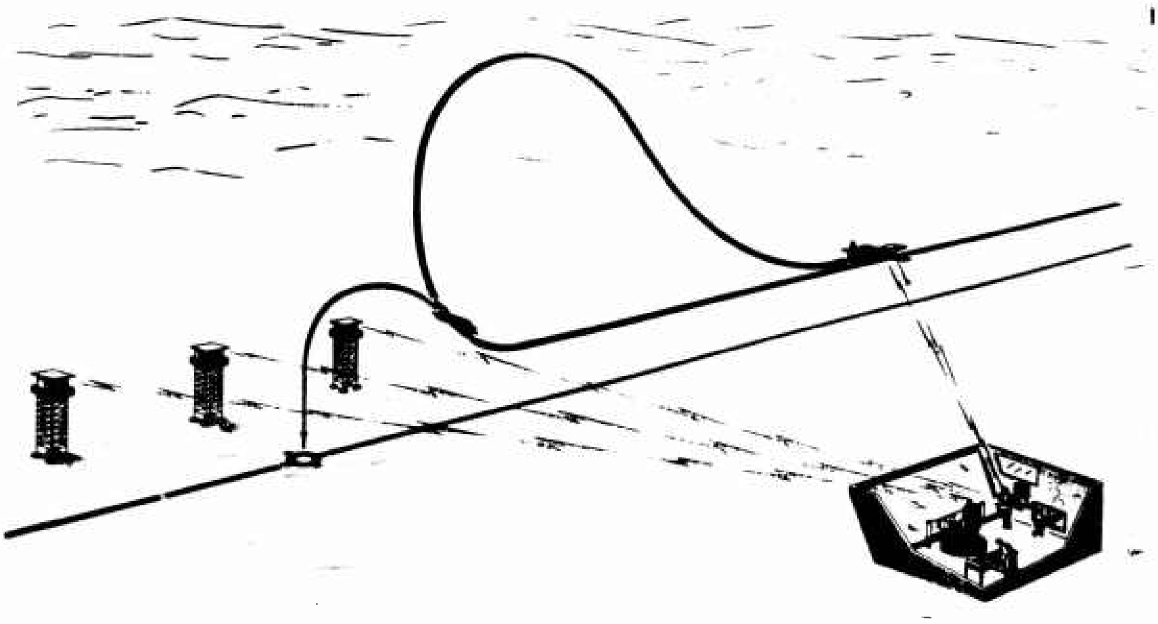

FIG. 1. Special-Weapons Delivery Flight Path.

Ranges presently in operation are located at Fallon, Nevada; El Centro, California;[1] Pinecastle, Florida; Kauna Point, Hawaii; Guantanamo Bay, Cuba;[1] Yuma, Arizona; Cherry Point, and Stumpy Point, North Carolina; Roosevelt Roads, Puerto Rico, for the Navy, and at Nellis Air Force Base, Nevada,[1] for the Air Force. A range was also instrumented for the United Kingdom at Tain, Scotland.[1] A range at Boardman, Oregon, for the Naval Air Station at Whidbey, is in the planning stage and is scheduled to be in operation by early 1969. The average squadron pilot, using the facilities of one of these instrumented ranges, is able to perform successfully low-altitude special-weapons delivery maneuvers after approximately 10 operational flights. By flying two eight-pass flights daily, the pilot can qualify for missions against actual targets in 5 days.

Although these range facilities were developed primarily for pilot training in special-weapons delivery, including pop-up and lay-down maneuvers, they are also used for training in dive bombing, electronic countermeasures, mine-laying plots and other conventional maneuvers. As new maneuvers are developed, the range instrumentation can be adapted for the necessary pilot training.

[1]These ranges use an optical tracker (Model 5) and plot aircraft in azimuth and elevation only.

RANGE REQUIREMENTS

SITE SELECTION

In selecting a range site, it is most important to establish the direction and accessibility of the flight line, the location of target center, and the site for the control building (Fig. 2). Aircraft should have sufficient air space over the flight line to allow the pilot to descend to an altitude of 100 feet when he is 50,000 feet from the target on the approach and to permit pull-up at least 25,000 feet beyond the target.

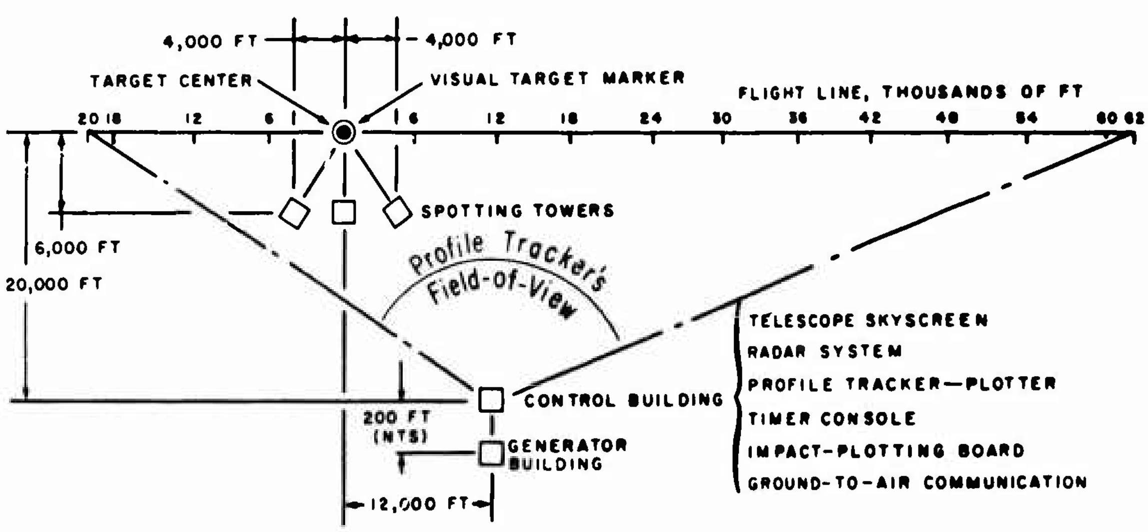

FIG. 2. Special-Weapons Delivery Range Layout.

For over-the-shoulder delivery, the bomb trajectory requires up to 30,000 feet elevation. The width of the air corridor should be 7,000 feet on one side of the flight line and 14,000 feet on the other to allow space for the pilot to circle while waiting for the next pass.

The minimum ground space layout should provide a radius of 1 mile around the target center. Provision should also be made for the location of three spotting towers parallel to the flight line at a distance of 6,000 feet, and spaced 4,000 to 6,000 feet apart. The control building site should provide an unobstructed view of the flight line. The flight line must have a background that contrasts with the aircraft, be free of moving objects such as automobiles, and be arranged so that the tracker operator does not look into the sun. The site should be within a 2,000-foot radius from a point 20,000 feet from the flight line and normal to a point 12,000 feet from target center. It may be situated on either side of the flight line. Aircraft flying along the flight line at an altitude of 100 feet must be visible to a man on-site observing the

aircraft through 7x50 binoculars. If the aircraft is not visible at all points along the flight line for a distance of 50,000 feet at this altitude, the control building must be elevated or a site on higher ground must be selected.

FLIGHT-LINE MARKERS

When a flight line has been selected, billboard-type markers 12 feet wide by 8 feet high and mounted 8 feet above the ground on posts, are installed to allow the pilot to orient himself to the target (Fig. 3).

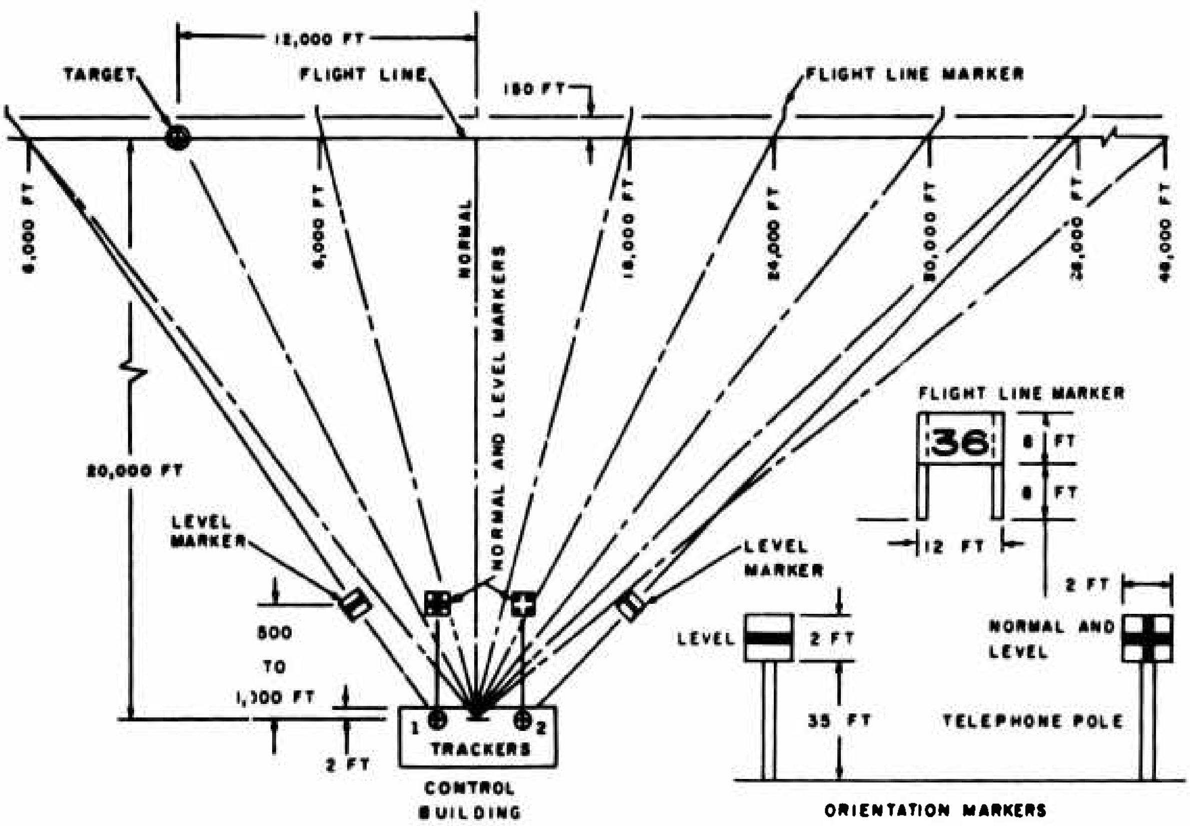

FIG. 3. Orientation Marking Devices and Flight-Line Markers.

The markers are placed 6,000 feet apart from a point 48,000 feet before to 6,000 feet beyond the target on a line 150 feet to the right of and parallel to the flight line. The markers face the aircraft as it approaches the target. The 150-foot offset enables the pilot to see the marker as he passes it on his right. A survey point on the centerline of the control building, 24 inches in from the front wall, is used to position the transit when the location of the billboards is being established. Each billboard, having numerals that indicate the distance to the target, is located on a line-of-sight from the subject point in the building through

6,000-foot increments on the flight line to the point of intersection with a line 150 feet to the right of and parallel to the flight line. Since the edges of the billboards are used to boresight the skyscreens, errors in the location of the billboards will be reflected in inaccuracies of groundspeed information received from the skyscreens. Therefore, all surveys should be of third-order accuracy.

If the flight line is inaccessible or over water, thus precluding the use of billboards for boresighting, a minimum of three reference points—zero (or target center), 15,000 and 30,000 feet from target—must be visible to the pilot so that he can align the flight path of the aircraft with the flight line as he begins his approach.

TARGET

The target must be visible to the pilot from a sufficient distance to enable him to maintain his flight path over the flight line. Visibility may be as limited as 18,000 feet with billboard markers located at 6,000-foot increments from the target. If reference points are used at 15,000 and 30,000 feet, the target must be visible from a distance of 40,000 feet along the flight line. A good reference marker consists of a banner about 30 feet long and 6 feet wide, made of seven 4- by 6-foot sheets of expanded metal, fire-orange in color and suspended vertically at a height of 30 feet by a steel cable stretched between two telephone poles that stand 50 feet apart (Fig. 4). The target reference banner should be

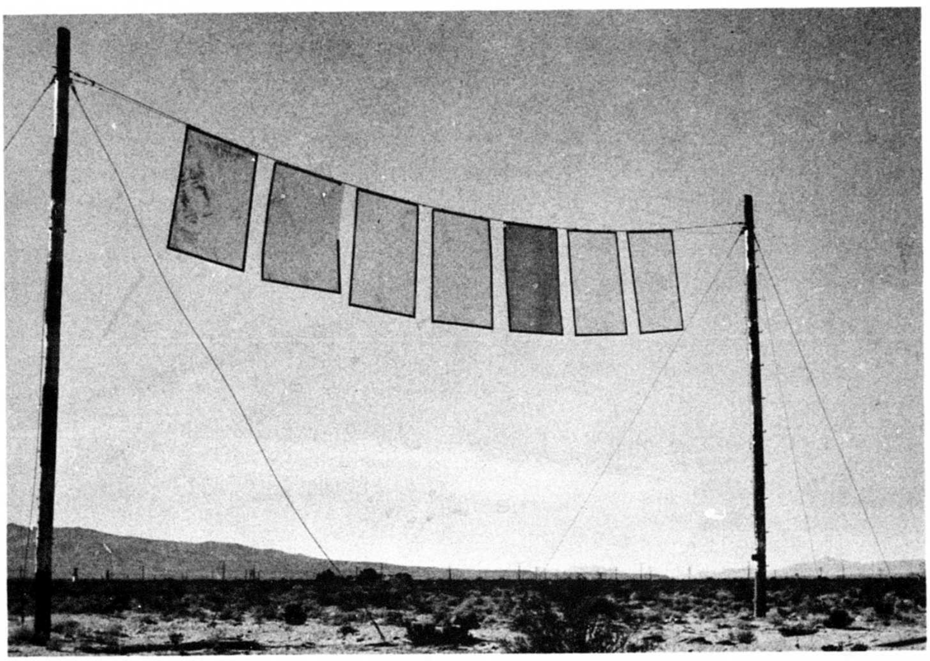

FIG. 4. Reference Marker.

located on the flight line about 1,000 to 1,500 feet beyond the target to minimize damage by bomb blast. A post approximately 20 feet high should be set at target center for use in boresighting both the impact-spotting equipment and the telescope skyscreens. Concentric rings of readily visible material, such as lime or old tires, at 100, 500, and 1,000 feet from target center are also recommended as an aid to the pilot in locating the target. The area should be sufficiently flat to enable each impact spotter to see every part of the target.

When aircraft have the capability of locating the target from great distances by radar, it is helpful if radar reflectors are mounted at target center to provide a stronger signal return. Two radar reflectors, covering approach angles from 20- to 60-degree elevation and oriented in the direction of approach, meet this requirement. If the ground target is approached from more than one direction, an additional pair of reflectors must be mounted at target center for each additional flight path that deviates more than 45 degrees from the primary flight line.

It is necessary to mount the radar reflectors on a 25-foot post at target center. Radar targets not located at target center might cause the aircraft radar to oscillate from one radar target to the other, thereby creating errors in the computer.

BUILDING REQUIREMENTS

CONTROL BUILDING

The control building (Fig. 5) is the range operating center, serving as the headquarters of the range engineer and the squadron representative who relays information to the pilots and suggests corrective measures to be taken to attain the required profiles and escape distances. The building should be at least 22 feet wide by 40 feet long to provide ample space for housing six skyscreens, two profile tracker-plotters, three radar cabinets, an impact spotting board, timers, and communication equipment. Cinder block, or similar construction material, is recommended for use so that heating and air conditioning will be efficient in a wide range of temperatures. The roof of the building must have a low pitch (about 12 - 2 or less) and be capable of supporting the 2,000-pound radar antenna at a point above the tracking console. If necessary, a post can be run through the roof from the lower deck to help support the antenna. The front of the building should have three 5- by 12-foot windows and be parallel to the flight line. If these windows are exposed to the summer sun, Type VI heat-absorbing glass should be used. However, since this

FIG. 5. Control Building.

type of glass greatly reduces skyscreen sensitivity, a 15-inch-wide panel of clear plate glass should be installed in the center window where the telescope skyscreens are mounted. Steel rollaway shutters to protect the windows are also recommended. Figure 6 shows the flight control center and illustrates a typical flight maneuver and the principal components in the control building.

GENERATOR BUILDING

When 60-hertz commercial power is available, a building about 10 feet by 14 feet is required to house a 25-kw motor-driven, 400-hertz generator for the radar. The building should be located 200 feet from the control building.

Rigorous voltage and frequency stability requirements, demanded by telescope skyscreens and other electronic equipment used in acquiring data for loft bombing, make 60-hertz commercial power extremely desirable. Generator failure usually results in loss of flights even though a standby unit is available. Generator voltage varies greatly, sometimes beyond the stabilizing capabilities of the voltage regulator. Most regulators will pass high-voltage pulses of up to 25 milliseconds duration. These pulses will produce incorrect data and may cause damage to the equipment. More accurate regulators are available with a recovery time of 1 hertz,

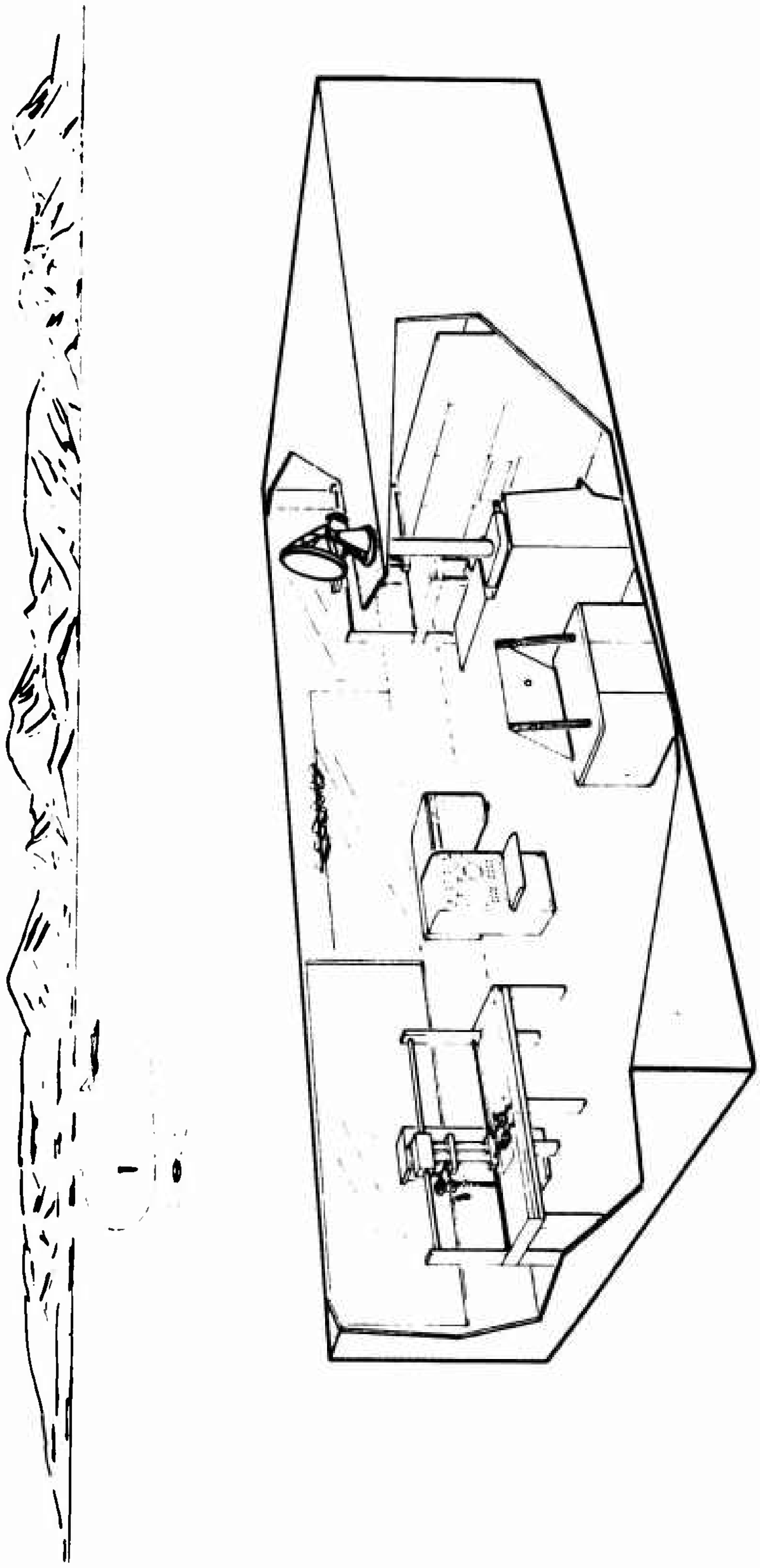

FIG. 6. Flight Control Building.

or 17 milliseconds, but even a pulse of this duration will trigger a skyscreen that has sufficient sensitivity to sense an aircraft at a distance of 5 miles or more. One of the timing devices is driven by a clock movement that is dependent for accuracy on a stable, 60-hertz frequency. A change in frequency of 1 hertz at the generator during the timing period will cause an error of 1.7% in indicated speed. This error is sufficient to cause a missile impact error of over 300 feet. However, such an error can be virtually eliminated by using a frequency standard that will hold the frequency within 0.001%.[2]

If commercial power is not economically feasible and the use of generators is necessary, the additional generators must also be installed in the generator building. The generator building should be 14 feet by 20 feet to house two 60-hertz, 75-kw engine-driven generators and one 400-hertz, 25-kw motor-driven generator. Power requirements are listed in Appendix A.

SPOTTING TOWERS

Three spotting towers, 6,000 feet from the flight line, are required for triangulation of the missile impact point. The buildings should be about 10 feet square with the front wall having a plate-glass window 6 feet wide by 4 feet high and 3 feet above the floor (Fig. 7). The location of the middle spotting tower should be normal to the flight line at target center, while the other two towers flank the middle one on a line parallel to the flight line and from 4,000 to 6,000 feet removed from the middle tower, with the front face of each building normal to the target (Fig. 2). These distances are minimum and represent the optimum arrangement, but are subject to change according to the local terrain. The main criteria for spotting-tower locations are: (1) the towers must be at a sufficient distance from the flight line and the target to ensure personnel safety, (2) visibility with respect to the total target area must be assured, and (3) separation must be adequate to provide good triangulation.

DESCRIPTION OF EQUIPMENT

TRACKER PLOTTERS

This range instrumentation greatly facilitates the training of pilots in weapon-delivery techniques that require accuracy, and it enables

[2]Such an instrument is available at American Time Products, Division of Bulova, 61-20 Woodside Avenue, Woodside, New York 11377.

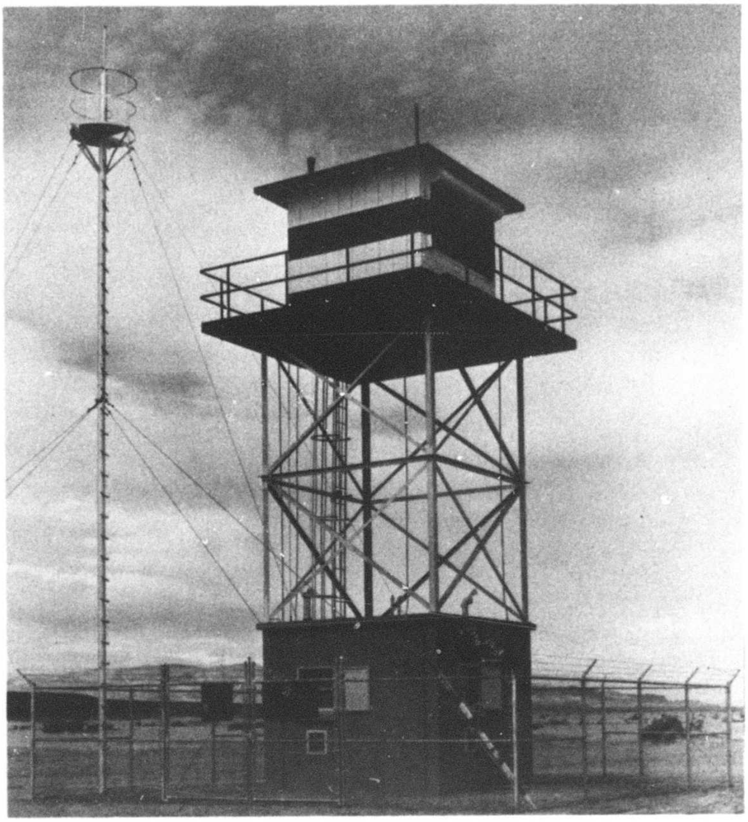

FIG. 7. Spotting Tower.

the specified training to be acquired in a minimum of time. Information provided by the equipment is available immediately and is relayed to the pilot at the end of each pass, enabling him to make corrections in his subsequent passes. To accomplish this function, two basic instruments were developed: the tracker-plotter and the skyscreens.

Optical

The optical tracker-plotter gives a profile of the flight maneuver. It was designed to enable the operator to follow the path of the aircraft through a pair of 7x50 binoculars and also to drive a hydraulic plotter that plots the path of the aircraft in the vertical plane of the flight line.[3]

Many pilots, particularly new pilots, have a tendency to drop a wing after losing sight of the horizon at pull-up, causing the aircraft to veer

[3]This tracker-plotter, designated as the Model 5, and described in NAVWEPS Report 8414, has been in use for several years at the ranges listed in the introduction, and is quite satisfactory for deriving a two-dimensional plot from the plotter.

from the vertical plane of the flight line. The two-dimensional plot of distance along the flight line versus elevation did not show this deviation, thus errors resulted. Therefore, a means of plotting distance from the vertical plane of the flight line was necessary to eliminate this error and radar was selected as the means of indicating the deviation from the flight line.

Radar

Aircraft approach at low altitude before making a loft-bombing delivery to avoid radar detection. It is difficult to distinguish the radar return signal of an aircraft target from the noise signal received from vegetation and ground return. This difficulty can be resolved only by knowing the approximate location and heading of the aircraft.

When an aircraft performs the loft-bombing maneuver, it usually approaches the target at an elevation of 100 to 200 feet above the ground. As stated above, at this elevation the radar receives strong signals from various objects near the flight line such as water towers, target banners and radar reflectors near the target, and small signals (ground clutter) from trees and vegetation. Since some of these signals present a stronger "target" than the aircraft being tracked, the radar may leave the aircraft and lock onto the stronger target. The antenna must be driven manually through these areas, preferably by following the aircraft's flight optically. The M-33 radar (Fig. 8) was chosen for tracking aircraft in the loft-bombing maneuver because it has an excellent optical system that operates on the same axes as the radar antenna. This enables the operator to track the aircraft by sight, driving the antenna through the ground clutter, using the aided tracking rate control provided for this purpose.

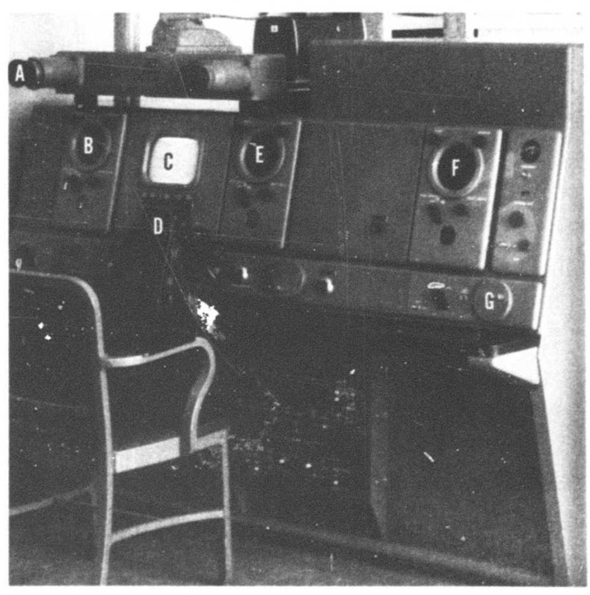

FIG. 8. M-33 Radar Tracker. (A) Optics system, (B) elevation scope, (C) TV monitor, (D) azimuth elevation monitor, (E) azimuth scope, (F) range scope, and (G) range control.

Tracker-Plotter Feasibility Study

During the radar-tracking feasibility study, hundreds of plots were made of aircraft flying loft-bombing maneuvers in training. Each flight was plotted simultaneously by the optical tracker in two dimensions and by the radar tracker in three dimensions. When the aircraft stayed close to the vertical plane of the flight line, the two plots almost coincided, indicating that each plotter followed the flight path accurately (Fig. 9 and 10).

Figure 11 is a plot of the path the aircraft appeared to follow when tracked by the optical tracker, based on the assumption that the aircraft was in the vertical plane of the flight line. Figure 12 is a three-dimensional plot by the radar tracker of the same flight. The range versus horizontal plot shows that the aircraft was as much as 800 feet beyond the flight line. The true position of the aircraft, as shown by the three-dimensional radar plot, is 500 feet in elevation and 500 feet in horizontal distance removed from the position plotted by the optical two-dimensional plot. The two-dimensional plotter allows this error to pass unchallenged and the pilot is not informed of the reason his missile missed the target or what correction is required to improve his accuracy.

While radar tracking eliminates the error due to deviation from the flight path, it does introduce other lesser errors. Range resolution is

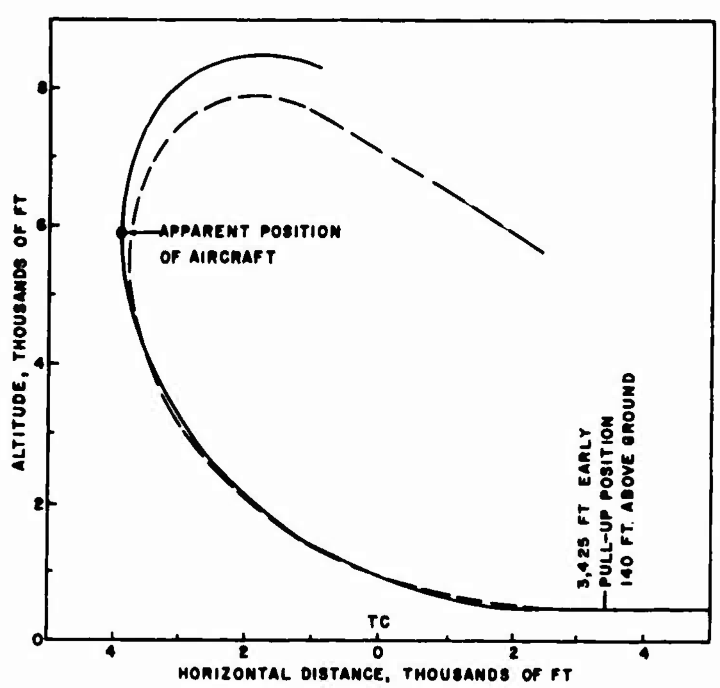

FIG. 9. Optical Tracker Pass No. 519. (Two dimensions.)

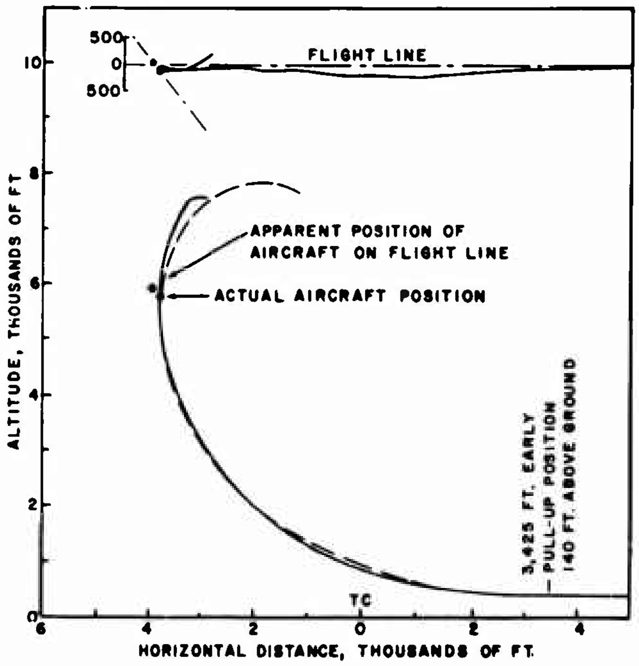

FIG. 10. Radar Tracker Pass No. 519.
(Three dimensions.)

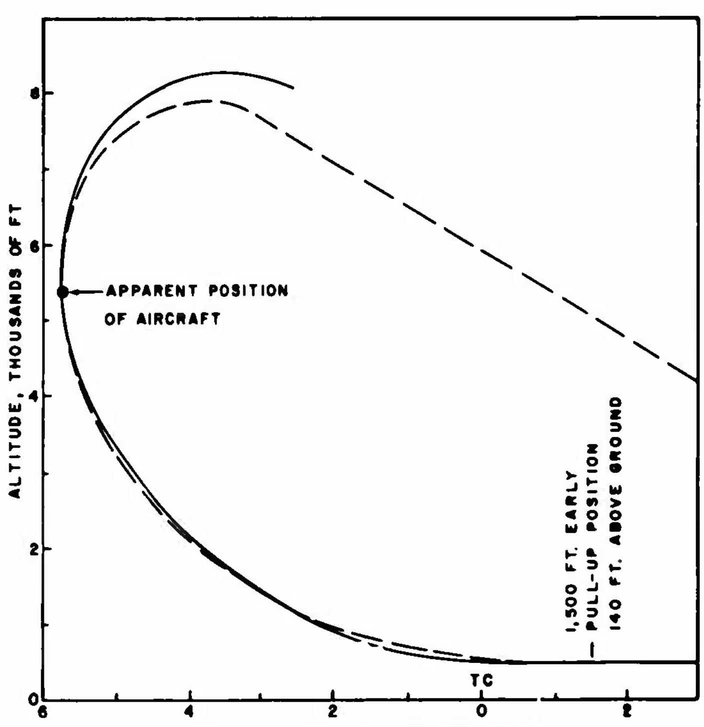

FIG. 11. Optical Tracker Pass No. 510.
(Two dimensions.)

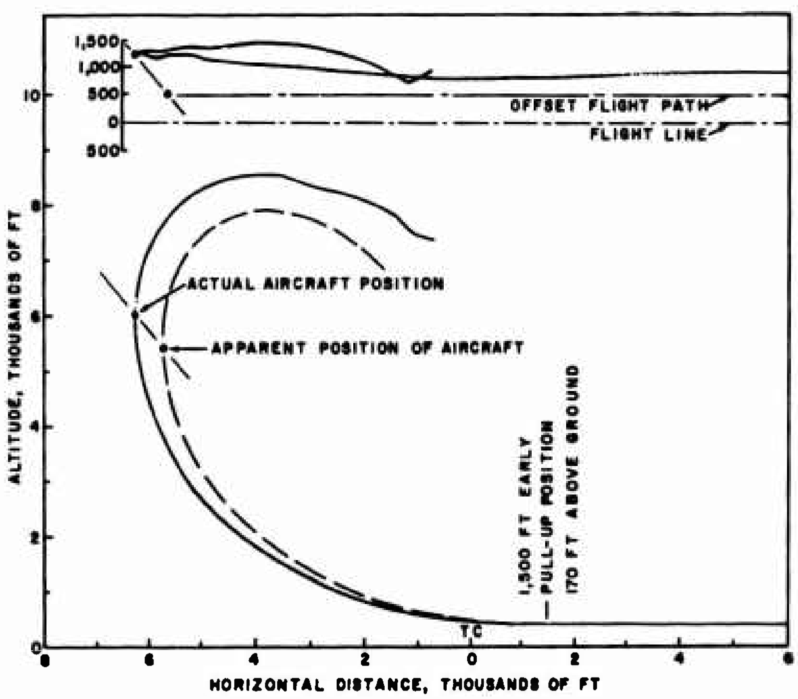

FIG. 12. Radar Tracker Pass No. 510. (Three dimensions.)

good up to ±30 feet, sine-cosine function potentiometers are accurate to 0.04%, and antenna tracking error may be 1.5 to 2 mils. Assuming maximum error to be accumulated in one direction, the total maximum error could be 75 feet or about 0.075 inch on the plot at the point of bomb release on the over-the-shoulder maneuver. Usually some errors would be plus and some minus, thereby reducing the probable overall error.

THE AN/FPS-102 SYSTEM

Components and Characteristics

The AN/FPS-102 system consists of the following:

1. A modified M-33 radar
2. Two Model 5 optical trackers
3. Two plotters
4. A timing console
5. Six skyscreens
6. Three impact-spotting quadrants (supplied without binoculars)
7. One impact-plotting board

All necessary equipment for electrical power, communications equipment, and aerological equipment used in conjunction with the AN/FPS-102 system, is provided by the facility using the equipment.

The AN/FPS-102 system was designed for plotting loft bombing on a specific flight line at a set heading for a maximum distance of 10 miles. However, other maneuvers such as pop-up, wingover, lay-down, and buddy bombing can be plotted. With the addition of an optical acquisition unit, dive bombing can also be plotted. However, in all these maneuvers, the aircraft must fly on a heading within ±10 degrees of the specific flight line heading and must be acquired optically. The AN/FPS-102A, to be discussed later, uses a M-33 radar acquisition unit and other circuit modifications that eliminate this requirement.

The M-33 Radar

Basic. The M-33 radar was selected as a means of tracking the aircraft. Tracking by radar requires two operators, one to track in azimuth and elevation, and the other to track in range (Fig. 8). Range information is received only by a signal (pip) on the oscilloscope screen provided for that purpose. Azimuth and elevation signals also appear on their individual oscilloscope screens, but since elevation and azimuth pips are on separate screens about 28 inches apart and cannot be seen simultaneously, the optical system is used for tracking in these axes.

The standard M-33 radar features a C-band radar for acquisition and an X-band radar for tracking. The tracking portion of the radar is the only part used in the AN/FPS-102 system. It can be operated in any one of three modes—manual, aided, or automatic—in any or all of the functions of range, azimuth, and elevation. Automatic tracking, with the exception of range tracking, is not often effective against low-altitude aircraft (below 200 feet) moving at high speeds; however, in the aided mode of operation, the tracking rates can be extremely smooth and accurate, and quite satisfactory for the plotting operation.

Modified. The M-33 radar was originally designed to plot in polar coordinates. It was modified to drive a remote plotter in cartesian coordinates to give position plots in three dimensions: elevation versus distance along aircraft line of flight (profile) and the aircraft heading (track).

The position of each of the two plotting pens is controlled by the radar by means of a Type-1 (position-sensitive) servo system. Radar signal voltages, representing range, azimuth, and elevation, are fed through the computers and summing amplifiers to the plotter drives. The pens plot position in three dimensions corresponding to the radar-target

position. The theory and operation of the M-33 radar tracking circuits not covered in detail in TM 9-6093-1[4] are discussed in Appendix B.

Characteristics of Plotting

Special-Weapons Delivery. When low-angle, medium-angle, lay-down and pop-up delivery maneuvers are plotted on a range with minimum ground return signals, the radar antenna controls can usually be put in standby position until the pilot calls in at the start of the run, usually at 50,000 feet from target center. The controls are then set in AUTOMATIC. The aircraft entering the gate locks in the antenna circuit and the entire maneuver can usually be plotted automatically. However, during the plotting of the over-the-shoulder maneuver, tracking must be done in the manual aided position until the aircraft rises above the horizon since the target area usually contains a number of spurious targets.

Dive Bombing. An optical acquisition unit (Fig. 13) has been designed for use with the AN/FPS-102 system in dive bombing maneuvers. The

[4]Anti-Aircraft Fire Control System M33C and M33D, Introduction of Theory and Operation. Department of Army Technical Manual TM 9-6093-1.

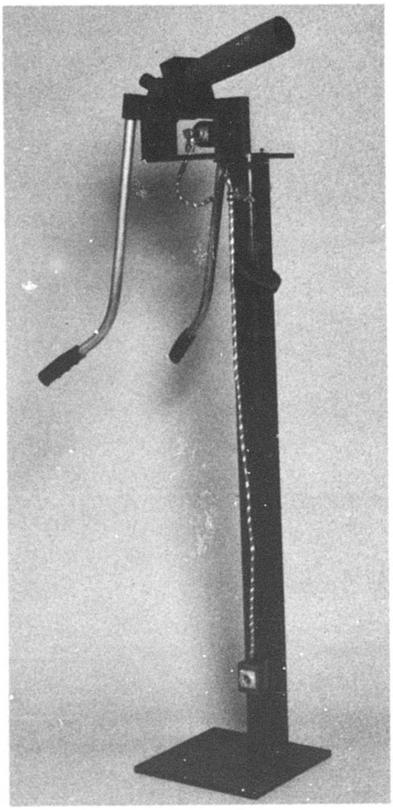

FIG. 13. Optical Acquisition Unit.

instrument contains two synchro transmitters, one for elevation and another for azimuth. These transmitters are connected to receivers in the radar antenna drive circuit. The transmitter and receiver are adjusted to null when the radar tracking antenna and the telescope on the acquisition unit are sighted on the same point.

When a plot is to be made, the aircraft in flight is located and the telescope on the acquisition unit is positioned to place the aircraft at the intersection of the cross hairs. The operator then tracks the aircraft. When the radar-tracker operator is ready, he actuates a switch that causes the antenna to slew to the same angular position as the acquisition unit. The range operator adjusts the range control until he sees the pip in the range gate. He then transfers control from the acquisition unit to the radar-tracker operator who plots the aircraft's path during the dive. When control has been transferred, the acquisition operator locates the aircraft that will make the next pass and follows it until it is transferred to radar-tracker control. By continuing this sequence, dive angles can be plotted by radar at 1-minute intervals.

AN/FPS-102A SYSTEM

A modified AN/FPS-102 system, designated the AN/FPS-102A, is not limited to a specified flight line heading but can plot aircraft position when approaching from any heading, making a true plot. An M-33 radar acquisition system is incorporated in the AN/FPS-102A system so that the aircraft can be located by radar when its position is unknown. However, when weather and other conditions permit, the optical acquisition is still used since it acquires aircraft faster than radar acquisition when the approximate aircraft position is known. An additional feature of the AN/FPS-102A system is a computer that continuously samples aircraft dive angle, elevation, and speed of approach to target. This information is displayed by illuminated numbers. On a tone signal from the aircraft radio, it is also printed for a permanent record. The printer will also print on command from the plotter operator. Information printed includes the date, aircraft pass number, dive angle, elevation, speed, and horizontal distance from aircraft to target. The printed sheet is torn off and stapled to the plotting sheet after each run. Radar acquisition, ability to plot from any heading, and increase of plotting scale to 6,000 feet per inch, gives the AN/FPS-102A system the capability of plotting evasive maneuvers, mine laying, and high-altitude bombing. Thus, range usage and versatility is greatly increased. Aircraft can be acquired in excess of 50 miles and tracked 25 miles.

MODEL 5 OPTICAL TRACKER

Uses

The optical tracker (Fig. 14) is still in use at most of the instrumented loft-bombing training ranges. Where the M-33 radar has been

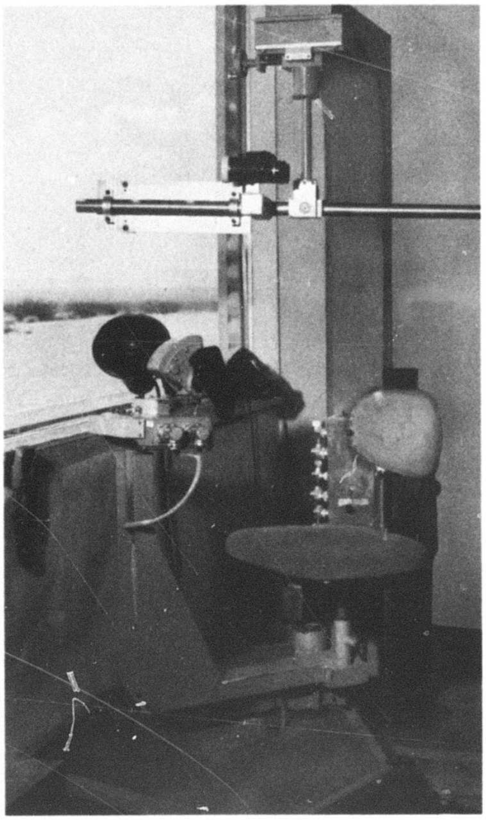

FIG. 14. Optical Tracker.

added to the system, the optical tracker is used primarily as a standby in the event of radar malfunction, and as a training device for new operators. It can also be used in conjunction with radar tracking when a plot of the trajectory of one of the larger missiles is required in addition to the maneuver profile of the delivery aircraft. If the pilot wishes to fly an offset course parallel to the flight line and up to 1,500 feet on either side of it to correct for crosswind effects, the tracker can be adjusted to compensate for this offset course.

Characteristics of Operation

When plotting the loft-bombing maneuver, the operator positions the tracker so that the field of view of the binoculars mounted on the tracker will cover a specified area on the flight line through which the aircraft must pass as it starts the maneuver. For most aircraft, this area is approximately 30,000 feet in front of the target at an altitude of 100 to 200 feet above the ground level.

A reticle, placed in the focal plane of the binoculars, assures reasonable accuracy in tracking. The dot in the center of this reticle

is 0.002 inch in diameter, the circle is 0.062 inch in diameter, and the vertical and horizontal lines are 90 degrees apart and 0.001 inch in width. The reticle is glass, 1 inch in diameter. All markings are etched into the glass. The operator attempts to hold the dot in the binocular reticle on the nose of the aircraft at all times while tracking.[5] Accuracy in the use of the optical tracker to plot the true position of the aircraft depends on: (1) the ability of the pilot to fly in a specified vertical plane for the entire maneuver, and (2) the ability of the tracker operator to continuously superimpose the dot in the binocular reticle precisely over a given point on the aircraft.

The Model 5 optical tracker has a gunsight aim-point camera (GSAP), Type N6A 16 mm, used during training of the tracker operator for monitoring his accuracy. Figure 15 shows the camera mounted on the vector arm of the tracker. The 15-inch-focal-length lens of the camera is boresighted on the same point as the tracker binoculars. If the tracking is accurate, projection of the film will show the aircraft in the center of

[5]For night training, the reticle is illuminated by a small, red light mounted near the left object lens of the binoculars. A rheostat controls the light intensity.

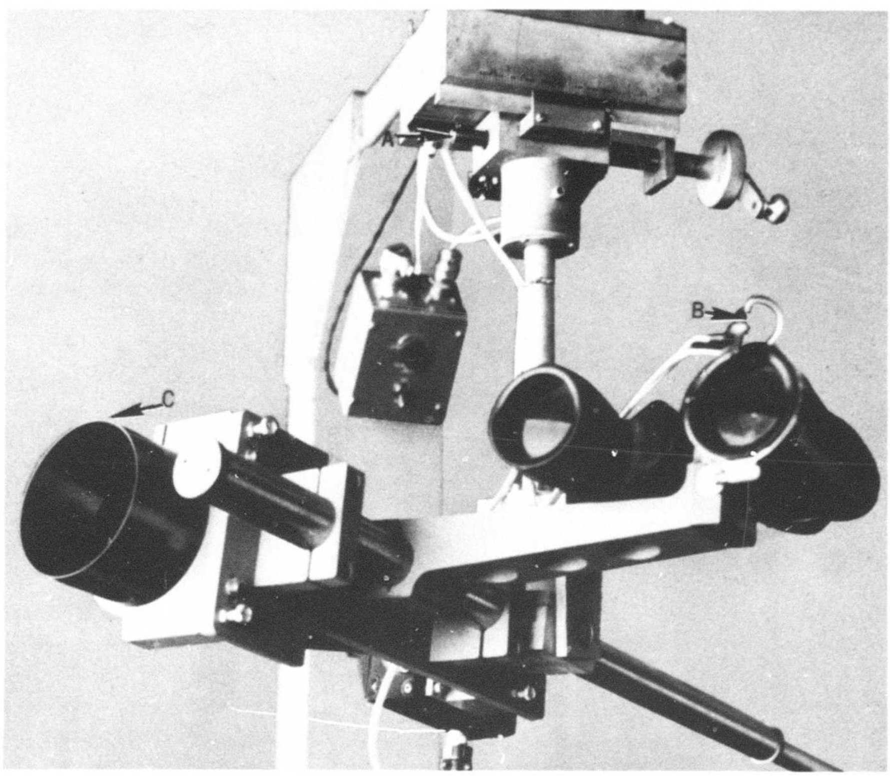

FIG. 15. Binocular and Camera Mount on the Optical Tracker. (A) Offset adjustment, (B) binocular light, and (C) GSAP camera.

the frame. Any deviation from the center indicates a similar deviation in the tracking from the aircraft. The amount of deviation can be scaled from the known size of the aircraft.

A tracker operator soon develops the ability to follow the path of the aircraft accurately, but as previously mentioned, the pilot may "drop a wing" after losing his horizon and veer from the vertical plane, causing an unacceptable error in the two-dimensional plot. Figures 11 and 12 show this error graphically.

TRACKER CONTROL

Optical

Optical tracker control is the type used in the machine-gun tail turret of the P2V aircraft. The control head has two control handles that the operator pivots on the horizontal and vertical axes to cause the binoculars to follow the aircraft in flight (Fig. 14).

As the control handles are pivoted left or right, a transistor circuit actuates solenoids that cause one unit of the dual hydraulic pump to drive the plotter-arm drive motor in the desired direction. When the handles are pivoted up or down, the other unit of the hydraulic pump drives the pen-carriage motor in the desired direction.

Radar

Radar control is by means of a servo system driven by the radar antenna. The servo system introduces voltages into summing amplifiers. The resultant voltages are applied to the solenoids of the hydraulic pumps and drive the pumps, as explained in the preceding paragraph. Feedback potentiometers, controlled by the plotter, introduce opposing voltages into the summing amplifiers. When the sum of the signal voltages and feedback voltages reach zero, the tracker stops. The feedback potentiometers are adjusted so that the null is reached when the plotter pen reaches a point on the plot that indicates the position of the target aircraft in space.

MODEL 5 FLIGHT-PROFILE PLOTTER

Basic Design

The Model 5 flight-profile plotter (Fig. 16) is a hydraulically driven unit designed on the principle of a pantograph with a ratio of 12,000:1 (1,000 feet at the flight line equals 1 inch on the plot).

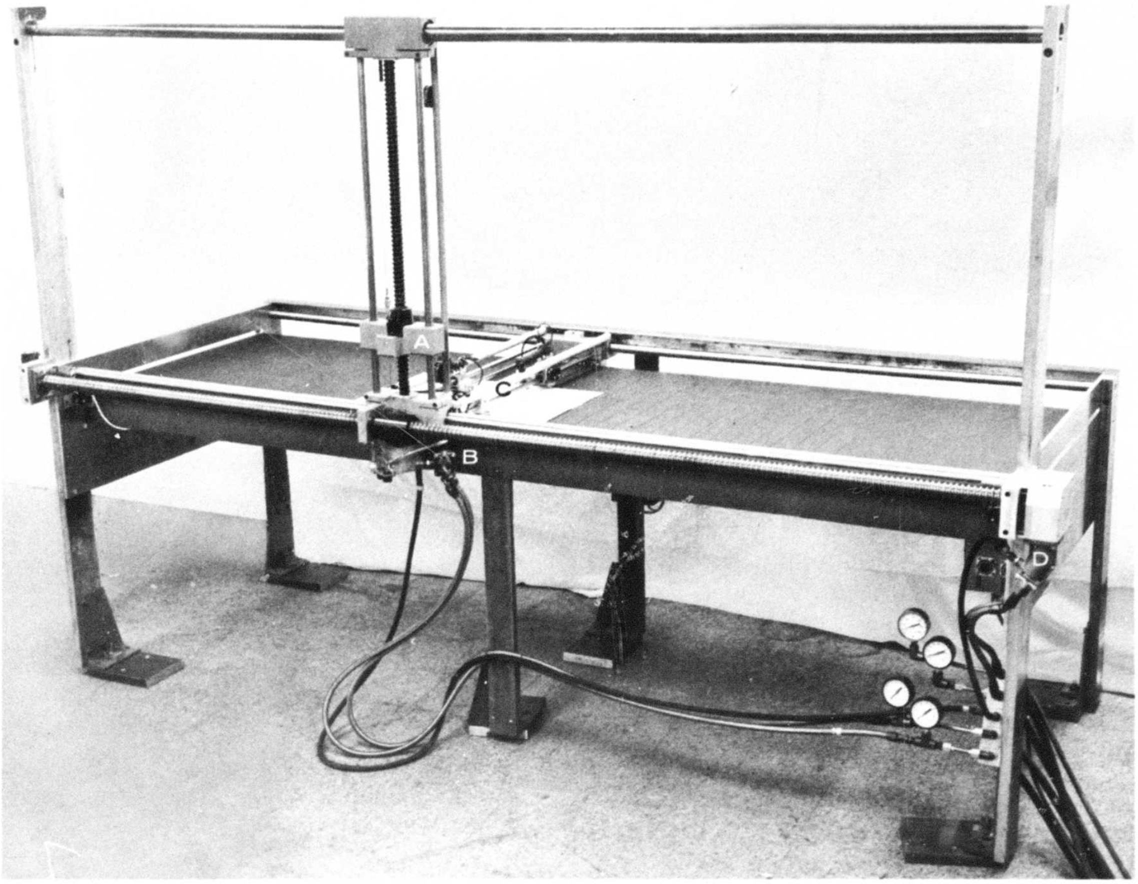

FIG. 16. Model 5 Flight Profile Plotter. (A) Vector block, (B) elevation motor, (C) carriage, and (D) azimuth motor.

The plot is in rectangular coordinates that plot elevation, Y, versus horizontal distance, X, and range, Z, versus horizontal distance, X.[6]

Each installation should have two plotters, one for plotting the path of the aircraft engaged in loft bombing, dive bombing, or similar maneuvers; the other to be a standby unit for training operating personnel. Either plotter can be operated by the tracking radar or by the optical tracker. The mechanical accuracy of the plotter is ±10 feet.

The plotter has two hydraulic motors. One motor drives a horizontal lead screw that moves the plotter carriage in horizontal direction, and the other motor, mounted on the plotter carriage, drives a vertical lead screw that moves the vector block in elevation (Fig. 16). The pen that plots elevation (X-Y axis) is mounted on the right side of the carriage

[6] Range (Z) versus azimuth (X) available only when plotter is driven by radar.

and is connected to the vector block by a steel cable through a series of pulleys. Movement of the vector block controls the pen in elevation. A second pen, driven by a servo loop between the radar and the plotter, plots the position of the aircraft in range (X-Z axis). It is mounted on a separate block on the left side of the carriage and is adjusted to contact the plotting sheet in the same horizontal position as does the elevation pen. Since both pens are mounted on the horizontal drive carriage, they maintain the same relative position horizontally on the plot (Fig. 17).

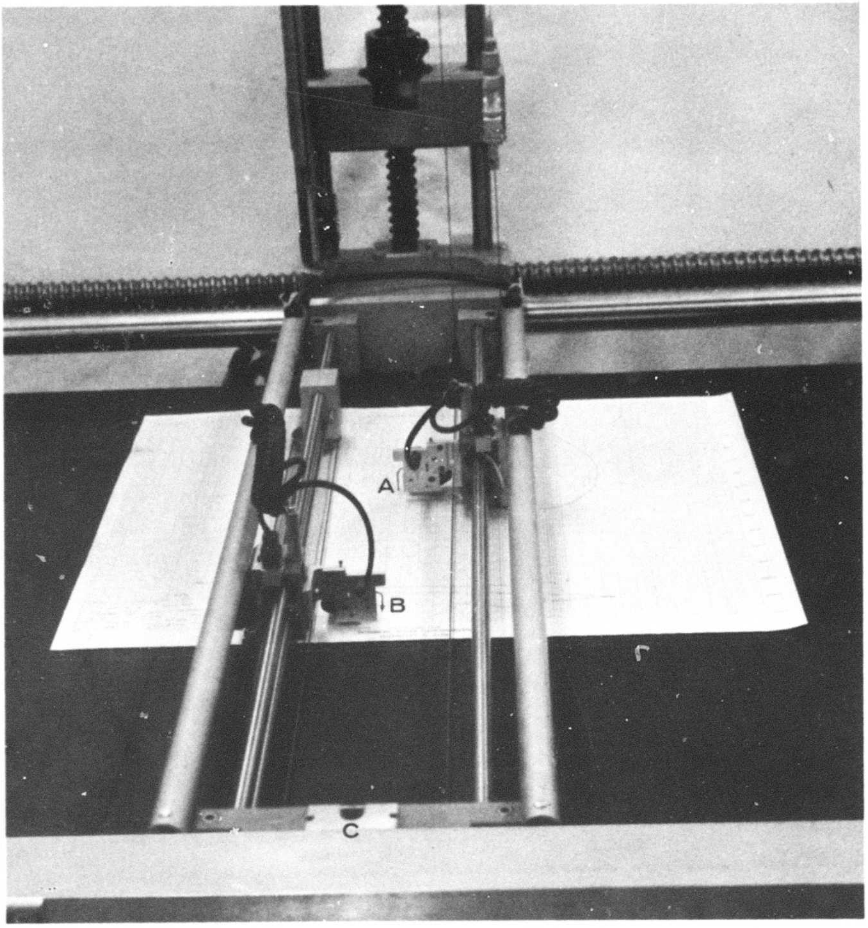

FIG. 17. Close-Up of Model 5 Flight Profile Plotter. (A) Elevation pen, (B) range pen, and (C) push button pen control.

Plotting Sheet Alignment

To plot the path of the aircraft accurately, a plotting sheet with grid lines spaced .010 inch apart and each line accentuated at 1-inch intervals is used. The sheet must be precisely positioned in both horizontal and vertical axes in relation to the target to be bombed. Since

the width of the margin on the plotting sheet may vary, alignment of the sheet on the plotting table must be made relative to the grid lines thereon and not the edge of the paper (Fig. 17). For this alignment purpose, a 0.015-inch steel cable is mounted close to the plotting surface, parallel to the horizontal lead screw, and extending to the full length of the plotting surface. This cable is positioned to represent either sea level, or approximate target elevation. The graph is located in elevation by positioning the graph on the plotter so that the entire length of the first horizontal grid line on the graph sheet lies under the steel cable. A pointer on the paper-positioning guide shows the required position of the first vertical grid line on the graph paper. A pin in the paper-positioning guide fits into any one of a series of holes drilled into a brass rail parallel to the horizontal lead screw (Fig. 17). Each hole represents a 1,000-foot increment from the target. A number that represents this position in thousands of feet is seen through a "window" in the face of the paper guide. A 15- by 20-inch graph sheet can thus be positioned to cover any 20,000-foot portion of the 80,000-foot flight line.

A vacuum chamber, machined into the top of the table immediately under the plotting surface, is actuated by the plotter operator after the plotting sheet is properly positioned, and this secures the paper until the plot is completed. The switch that actuates the vacuum also arms the plotting pens so that they can be operated by the penlift switches.

One training requisite is to ascertain the position of the delivering aircraft at the time of bomb impact to ensure that it is at a safe distance from the blast area. This is referred to as the full-escape maneuver, and it is plotted on a 15- by 48-inch graph sheet. This graph represents a distance of 48,000 feet along the flight line.

Penlift

The paper-position guide also operates the penlift switch. This, in turn, energizes the pen solenoid as the pen plots in the direction of the line of flight. The pen plots only while in contact with the paper and is lifted clear of the plotting surface by the penlift switch as the pen approaches to within 1/2 inch of the edge of the paper. A similar switch performs the same function in the vertical direction of the plot in either elevation or heading, thus preventing damage to the pen. The pen is operated automatically only when the 15- by 20-inch graph sheet is used. For large plots, it is operated manually by the plotter operator, who uses a push-button switch mounted on the horizontal crosshead (Fig. 17).

Tracker Selection

Since either plotter can be driven by either radar or optical tracker, each is equipped with a switch by which the desired tracking system is selected. This is a three-position switch with a standby position so that the radar does not drive the plotter past its limits

when it is being used to search for aircraft beyond the area covered by the plotting table.

AUXILIARY SPEED-SWITCH SYSTEM

Speed switches are used on the plotter to augment the skyscreen system and check it for measuring groundspeed (Fig. 18). In the speed-

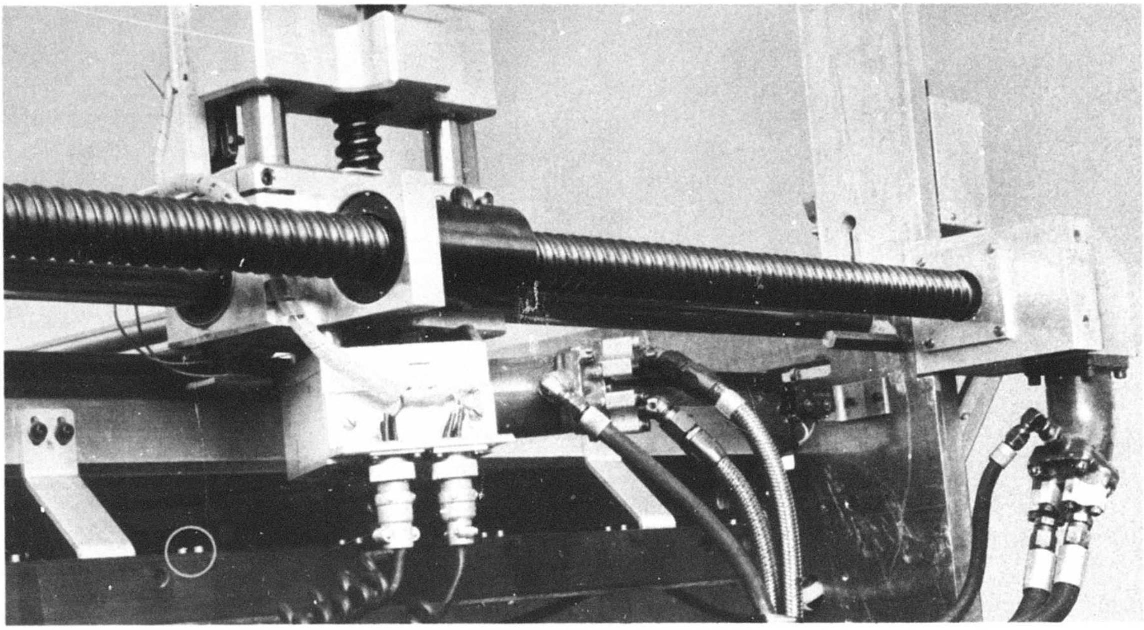

FIG. 18. Plotter Speed-Switch System. One pair of switches indicated by circle.

switch system, pairs of cadmium-plated screws are spaced 6.000 ±0.002 inches apart on a bar with a total accumulated tolerance of 0.003 inch. The bar is mounted on the horizontal axis of the plotter. The cadmium-plated screws provide electrical pulses as the tracker's line-of-sight intersects discrete points on the flight line. The speed switches are oriented by sighting the tracker binocular reticle on target center and adjusting the speed-switch bar so that the switch representing target position makes contact as the dot in the binocular reticle covers the post at target center. After the time interval between the pulses from any two consecutive switches is measured on an electronic timer, the groundspeed of the aircraft can be determined by referring to a nomograph relating the time interval to distance traveled in knots. The elapsed time is automatically measured and displayed by the electronic timer until it is reset. The accuracy of this system is ±1%, or within 10 ft/sec at 600 knots; however, over-all accuracy depends on the ability of the operator to keep the tracker oriented on the same point of the aircraft as

the switches make contact at the start and finish of the speed run. Although the speed switches are not as accurate as the skyscreens in measuring a speed run, they have one advantage. They operate on the same pantograph system as the tracker and are adjusted with the tracker for flight offset from the flight line. Further details on the Model 5 tracker are discussed in Appendix C.

The tracker speed switches can be substituted for the skyscreen by the selector switch shown at the lower right-hand corner of the timer panel. All electronic timer functions remain the same whether the skyscreen or the speed-switch system is used.

SKYSCREEN SYSTEM

The system consists of a group of six skyscreens mounted horizontally on a common rack near the ceiling of the control building. This permits a view of an area 20 feet wide and 200 feet high in the vertical plane of the flight line. A skyscreen is boresighted on each flight line marker from 30,000 feet to target center (Fig. 19). It is then raised to cover an elevation of 50 to 250 feet above the flight line.

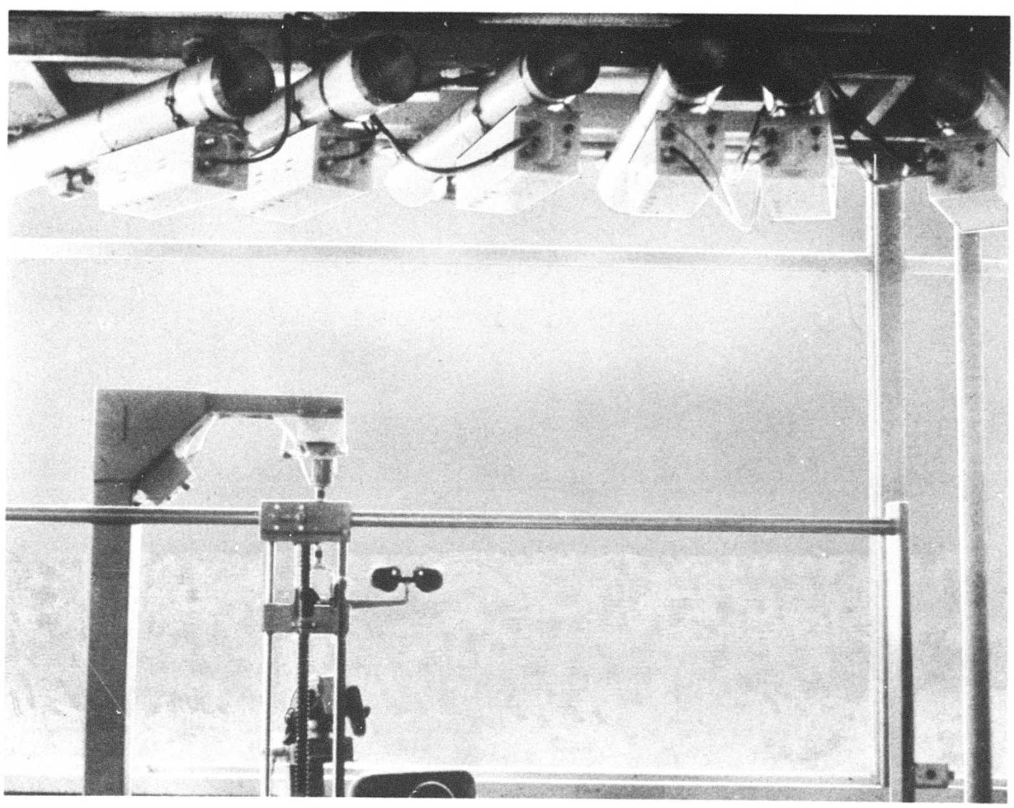

FIG. 19. Skyscreen System.

The skyscreen operates by a change in ambient light striking the grid of the photomultiplier tube. Skyscreen sensitivity is adjusted by changing the anode voltage to the photomultiplier tube. The adjustment, made at the power supply on the timing console (Fig. 20), accommodates changes in atmospheric conditions, background contrast with aircraft, changes in ambient light due to cloud coverage, and noise due to heat-wave turbulence. As the aircraft passes through the field of view of the skyscreen the change of light on the phototube starts an electronic timer. As the aircraft passes through the field of view of the next skyscreen, the timer stops. The elapsed time in seconds is converted to speed in knots by the use of a nomograph. True airspeed is measured by averaging two runs in opposite directions or by revising groundspeed for known wind velocity and direction. Data provided by the skyscreen are accurate only if the aircraft flies directly over the flight line during the timing period.

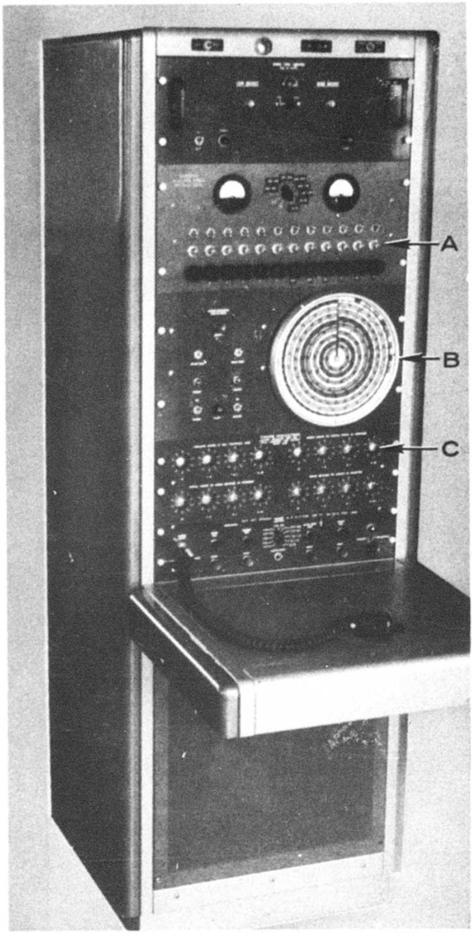

FIG. 20. Timing Console. (A) Skyscreen power supply, (B) mechanical timer, and (C) electronic timer.

The accuracy obtainable with the skyscreen system in the measurement of aircraft groundspeed is within 2 ft/sec for speeds to 1,000 ft/sec or 592 knots.

The skyscreen system is more accurate, so it is used in preference to the speed-switch system whenever possible. However, since the skyscreen is more susceptible to false readings due to changes in ambient light, to atmospheric turbulence due to heat waves, and to triggering by birds or other forms of interference, it is advisable to use the speed switches concurrently as a backup system. The groundspeed reading triggered by the skyscreen can be registered on the electronic timer, which reads in seconds; the speed switches can operate the mechanical timer, which reads directly in knots. These functions can be interchanged by the tracker skyscreen switch (Fig. 21). Other problems inherent within the telescope

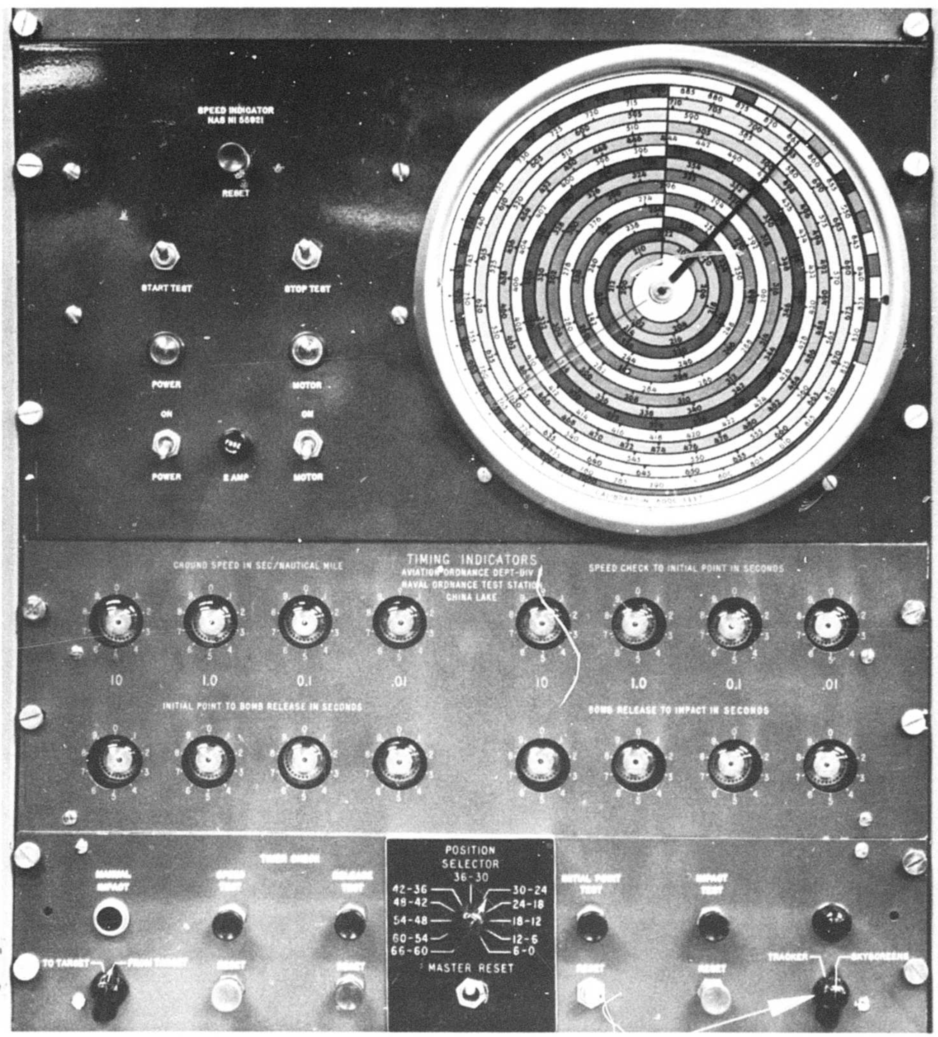

FIG. 21. Timers. (Arrow indicates skyscreen selector switch.)

skyscreen are the difficulty of boresighting in wooded areas, and spurious triggering signals received by the vibration of the control building. This is particularly true when the control building is located on a 75- or 125-foot tower, as is the case at Norfolk and Pinecastle. For more detailed information on the skyscreen system see Appendix D.

TIMING SYSTEMS

Two timing systems are used: an electronic timer and a mechanical timer. The latter is a clock calibrated to read aircraft speed in knots (Fig. 21).

Electronic Timer

The electronic timer uses a 200-hertz temperature-compensated fork for a time base, with a maximum error of 0.001% or 1:100,000. The timer is divided into four units, each of which counts up to 99.99 seconds in 0.01-second increments.

Figure 22 shows the timed increments of the loft-bombing maneuver.

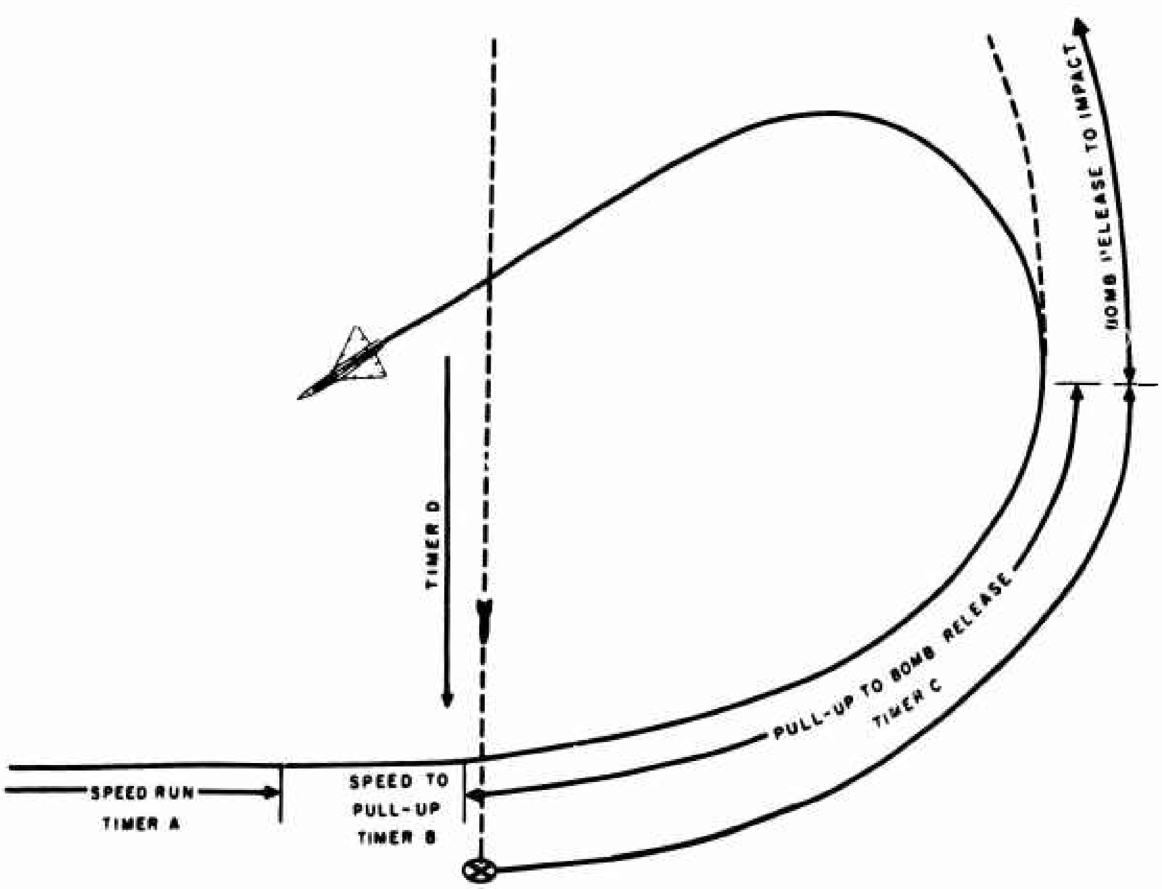

FIG. 22. Loft-Bombing Maneuver Timed Increments.

As the aircraft enters the field of view of a skyscreen, it causes a pulse to be emitted that starts the first of the four units in the electronic timer. As the aircraft passes through the field of view of the next skyscreen, the emitted pulse stops timer unit A and actuates timer unit B. The time recorded by unit A is checked against a nomograph to give aircraft groundspeed in knots. Timer unit B records the elapsed time from the end of the speed run, a known point, to the start of pull-up into the loft maneuver. A tone transmitted by the aircraft at the start of pull-up stops timer unit B and actuates timer unit C, which runs until the tone is terminated at bomb release. Termination of the tone stops timer unit C and actuates timer unit D, which measures elapsed time from bomb release to bomb impact. Timer unit D is useful in checking the position of the aircraft at the time of impact to determine if it will be clear of the blast area.

<u>Mechanical Timer</u>

The mechanical timer (Fig. 21), a clock that is started and stopped by pulses from the telescope skyscreen or the tracker speed switches, is calibrated to read speed in knots. The speed calibration is based on intervals of 6,000 feet. The clock face is designed in the form of a 15-turn spiral with each turn being 1/4-inch wide and in a different identifying color. All the color spirals begin and end on a vertical radius line on the face of the clock. This line designates the zero or reset position. Along the circumference of the clock face is a 1/4-inch band divided into 6-degree segments. The color of the first segment corresponds to that of the outside turn of the spiral, and each succeeding segment (reading clockwise) is color-matched to each consecutive spiral turn. The slow hand of the clock, making one revolution per minute, points to a color segment that identifies the spiral to be read, while the fast hand, making one revolution per second, points to a number on the spiral that represents the speed of the aircraft in knots. Figure 21 shows a speed of 535 knots. The clock is used primarily with the auxiliary speed switch system as a backup for the skyscreens and the electronic timer in measuring aircraft groundspeed.

The clock is driven by a 60-hertz synchronous motor and is susceptible to frequency variations. If generator power is used, a frequency stabilizer in the AC supply to the clock motor must be used to ensure correct timing.

IMPACT-SPOTTING QUADRANT

To ensure accuracy, impacts are observed by spotter operators from three spotting towers. (See Fig. 1 for tower location.) Position indication of impact is obtained by triangulation. The spotter rakes the target area with an impact-spotting quadrant equipped with a telescope, or a pair of binoculars, having a cross hair reticle (Fig. 23). A total rake angle of 37 degrees covers a 2,000-foot radius around the target

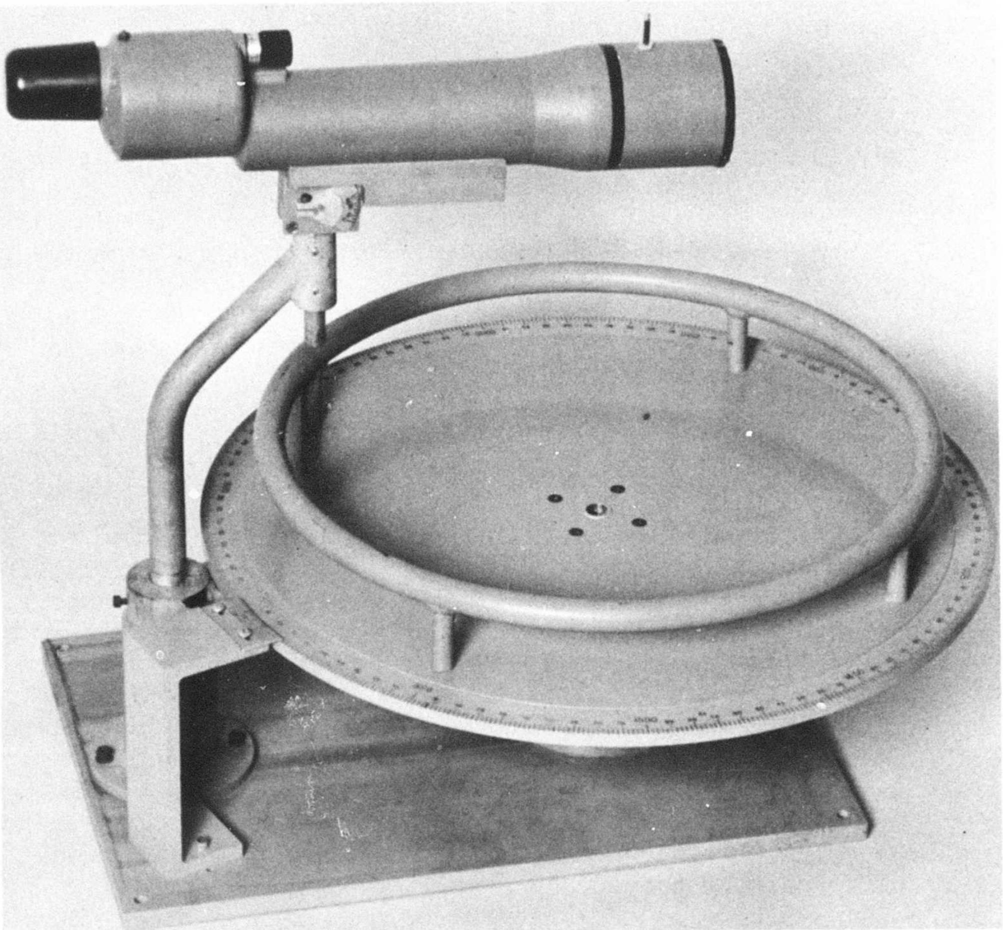

FIG. 23. Impact-Spotting Quadrant.

from a distance of 6,000 feet. A 6:1 gear ratio is used on the rake to expand the scale for more accurate reading. The smallest scale divisions are 0.112 inch apart and indicate 2 mils of angle. A vernier incorporated into the system allows a reading to 1/4 mil, representing 1 1/2 feet at a distance of 6,000 feet. The scale reads from 1,000 to 2,100 milliradians and is adjusted so that target reads 1,600 mils. Plus or minus readings as a source or error are thus avoided, since every reading is positive.

IMPACT-SPOTTING BOARD

Each spotting tower maintains communication with the control building by telephone, intercom, or radio. Each spotter operator calls his quadrant readings to the impact recorder in the control building who records the data on his spotting sheet and plots the impact point on the impact-spotting board (Fig. 24). The board is laid out the same as the actual target area on a scale of 200 feet to the inch.

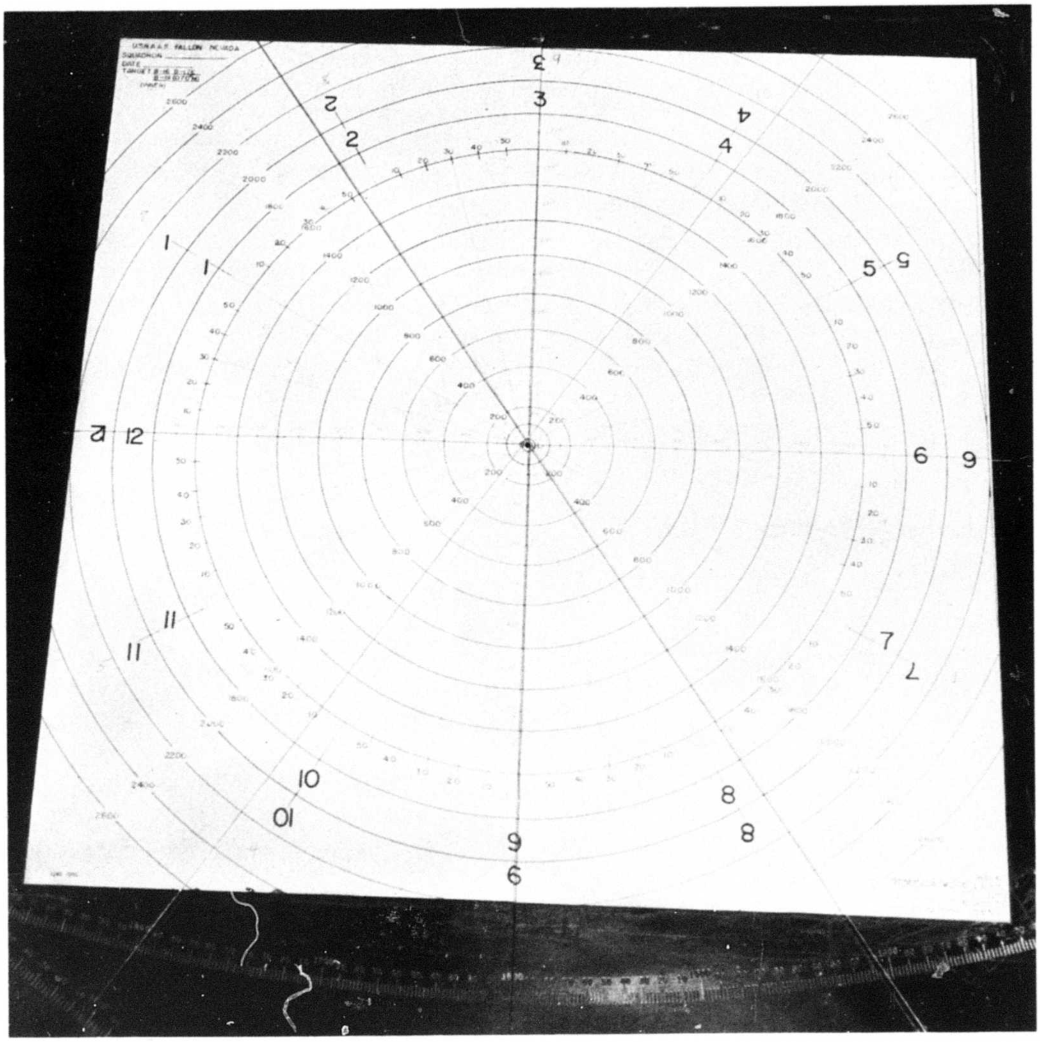

FIG. 24. Impact-Spotting Board.

The original impact-spotting board designed for this system, which is still in use at some ranges, has lucite arms for plotting impacts. The arm is pivoted from a point representing the position of the spotting tower in relation to the target, and extends beyond the target position to a scale graduated in 2-mil divisions. Three arms are used to represent the three spotting towers. When the arm passes through target center on the plotting sheet, it also passes through the 1,600-mil graduation on the position-indication scale. In this way, the reading from the impact spotter represents the same position in relation to the target as shown by the arm on the spotting board. On later model boards, the arms have been replaced with nylon fish lines, one end weighted and the other end held in place by magnets. The point at which the three lines intersect is much easier to mark, since the lines are only about 0.015 in diameter. The magnets are less cumbersome and much easier to handle.

After the point of intersection is marked on the plot, a scale, with a pin that fits into a hole at target center, is used to measure the distance of the hit from target center. Impact information is given in distance and clock position, i.e., 230 feet at 10:30.

COMMUNICATION EQUIPMENT

Two AN/GRT-3 radio transmitters and two AN/URR-35 radio receivers are recommended for communication between the pilots and the control-building operator. One of each of these is for standby use. Telephonic or intercommunication equipment for contact between the spotting towers and the control building is also needed. If the towers are not accessible to land lines, narrow-band FM radio has been found quite satisfactory.

STANDARD AEROLOGICAL EQUIPMENT

Since accurate wind information from the surface to 10,000 feet must be available to the pilot at all times, standard aerological equipment is required. Wind information is particularly important if passes on the target cannot be made alternately from opposite directions. This is especially true in the over-the-shoulder delivery at altitudes where winds have a noticeable effect on the trajectory of a bomb.

The principal items needed for standard aerological equipment are a theodolite, pibal balloons, helium tanks for inflating balloons, a recording anemometer, standard weights for balloons, and an aerological plotting board. Winds aloft can also be measured by putting X-band chaff in a helium-filled pibal balloon and plotting its path by radar. However, this is a time-consuming process and not recommended when the range is heavily scheduled.

RANGE OPERATING PROCEDURES

INITIAL PILOT INSTRUCTION AND TRAINING

All squadron members receive a complete briefing on range layout, method of operation, danger areas, and local conditions, as well as a special briefing on new maneuvers to be practiced. During preliminary training, a pilot is concerned with learning to maintain the specified groundspeed and fly the required profile. After he has mastered these, he proceeds to learn bombing techniques.

A pilot's first flight is made over the flight line to calibrate the aircraft's airspeed indicator in a series of straight and level runs made alternately in opposite directions to cancel wind effects. He then begins training in the over-the-shoulder delivery maneuver, a flight pattern including all the release angles that must be known for loft bombing. This is followed by training in 20-, 40-, and 50-degree loft-bombing maneuvers, and the escape maneuver for each type of delivery.

CHARACTERISTICS OF THE MANEUVER

During the maneuver, a tone or audio signal, initiated when the pilot begins his pull-up and terminated at bomb release, is transmitted via the aircraft's radio to a receiver in the control building. The audio signal nal energizes a relay that operates the electronic timer, causing the plotter pen to lift once for a 1/4-second period when the tone starts, and again when the tone stops. An accurate profile of each pass is made on the plotter. This is compared to an optimum profile drawn on the profile sheet by means of a template which is positioned by the "tone on" gap in the profile. Possible errors made by the pilot, together with pointers on corrections required, are communicated to him immediately by the range control officer or the squadron representative. This information includes checking on six points: (1) actual pull-up point as indicated by the tone, relative to correct pull-up point, (2) the position of the actual profile, relative to the true profile at 45 degrees, (3) the 90-degree point, (4) at top of profile, (5) at the release point, and (6) at the impact point. All this is recorded on the profile sheet along with the date, time, squadron, type of ordnance, type of delivery, sky cover, wind, temperature, pilot, aircraft, pass and round number, groundspeed, time from speed run to pull-up, time from pull-up to release, and time from release to impact. The name of the tracker operator should be entered on each profile sheet for reference and all data should be double-checked. The data sheets are given to the squadron representative at the end of the day's operations and are made available to each pilot for study.

SQUADRON RESPONSIBILITIES

Members of the squadron should be encouraged to visit the control building to watch the plotting of profiles and the maneuvers of other pilots. Squadron personnel should learn enough about the equipment and its operation to gain confidence in the range and in its data-gathering techniques.

The squadron commander of the unit using the range should give the range engineer a complete schedule of operations for each succeeding day. This schedule should include the type and number of aircraft, the pilot identification, the number of passes scheduled, the type of ordnance, the type and sequence of maneuvers, and the pull-up point of each maneuver.

With this information, the range engineer can set up all equipment needed and be prepared for the scheduled operations.

RANGE PERSONNEL REQUIREMENTS

A range requires a minimum of twelve men. It is important to have a well-trained and well-supervised crew responsible for the generation of complete and accurate data on each flight. A competent crew will inspire squadron confidence in data received, thus encouraging full use of the range facilities.

RANGE ENGINEER

The range engineer is responsible for the range equipment, operations, and personnel. He will decide on the number of aircraft allowed on the range at one time, the frequency of passes, and all matters relating to range usage. In the absence of a squadron representative, the range engineer also transmits plot information to the pilots.

ASSISTANT RANGE ENGINEER

The assistant range engineer controls range air traffic, enforces range safety requirements, briefs incoming pilots on the maneuver to be practiced, and transmits pertinent information via radio. He should be able to fill any operational position in an emergency and assist the range engineer when necessary.

TRACKER OPERATORS

Two tracker operators are required for either radar, or optical tracking. In radar tracking, one operator controls the radar in elevation and azimuth, and the other controls it in range. Radar tracking skill is not as difficult to acquire, nor does it require the fast reflexes that are necessary with optical tracking. Optical tracking requires extraordinary qualifications and training. Here, accuracy of plotting and recording groundspeed rates, when the auxiliary speed switches are used, depends on the skill of the operator. The most difficult part of optical tracking occurs as the aircraft pulls up, as elevation and horizontal distance are changing simultaneously. This is done in the automatic mode with the radar. Optical-tracker operators can be

trained on the second tracker during regular range operations while experienced operators are making the required profiles via radar or on the other optical tracker. The trainee's progress can be checked by the use of the previously mentioned gun-sight camera.

PROFILE-PLOTTER OPERATOR

One operator can operate both profile plotters. His duties are the placing of the paper-positioning guide for the scheduled maneuver and pull-up point, positioning the plotting paper correctly on the plotting table, checking the pen for ink flow, checking the position of the pen on the plot by boresighting the tracker on target center, and checking each plotting sheet placed on the tracker for complete and accurate information. As each profile is made, the operator writes in the time of pass, pass number, type of delivery, pilot's name, aircraft number, and round number. As each profile plot is completed, he turns off the vacuum and pen switch and gives the plot to the squadron representative, or range engineer, who draws in the optimum profile, completes the information block, and transmits the information to the pilot. The plotter operator manually actuates the pen when making the large plots for full-escape maneuvers.

TIME RECORDER

One man is required to operate the console and record the time from the electronic timer and the clock. He uses a nomograph to convert speed in seconds to speed in knots. He must know what the pull-up point will be for each maneuver; with the position selector he must select the speed switches or skyscreens positioned on the flight line at points closely preceding the pull-up point. After recording the time intervals, he resets the timer, leaving the master reset switch in the standby position until the next pilot calls in at the start of his run. Then he sets the master reset switch in the upper position to arm the circuit. Whenever it is necessary, he adjusts telescope skyscreen sensitivity to prevent the telescope from erroneous tripping before the aircraft starts its speed run.

IMPACT SPOTTERS

As previously stated, three spotters are necessary to obtain the triangulation data needed for accurate position indication. Speed and accuracy in spotting is acquired only with practice. The spotter uses the impact's smoke puff or dust cloud, before its dispersion by wind drift, as a reference for spotting alignment. After sighting the quadrant on the point of impact, he records his reading to an accuracy of 1 mil and reports the reading to the impact recorder in the control building. Each spotter must record his reading for future reference.

IMPACT PLOTTER

The impact plotter in the control building records the spotter's reading from each tower and plots the intersection point on the spotting board. Frequently, the lines will not intersect exactly and a small triangle will result, in which case the center of the triangle is assumed to represent the impact point. A relatively large triangle indicates inaccurate spotting; in such cases, the impact plotter should recheck the impact data readings with the spotters. As each impact is plotted, the distance from the target and the position in reference to clock position, e.g., 150 feet at 4:30, is recorded on the profile by the impact plotter and transmitted to the pilot.

RADAR TECHNICIAN

A full-time radar technician should be included in the range crew for preventive maintenance as insurance against inoperative time caused by operational breakdowns and delays. Since much of the range instrumentation consists of plug-in units, a technician can repair the majority of breakdowns with minimum interruption of operations. He can also substitute, as necessary, for various members ot the range crew.

AEROLOGIST

It is the duty of the aerologist to measure winds aloft at 60- to 90-minute intervals with changes being interpolated between these periods. Readings are taken every 1,000 feet of altitude up to the maximum height of the maneuver or the missile.

When the range is heavily scheduled, flights may start at 60- to 70-second intervals over a period of several hours. In this event, one member of the crew, usually the aerologist or the radar technician, makes up profile sheets in advance, filling in all the pertinent data, such as squadron, type of ordnance, cloud coverage, etc. Each member of the crew should learn the functions of as many positions as possible so that jobs may be rotated to decrease fatigue.

CONCLUSIONS

On an instrumented range of the type described, the average squadron pilot is able to perform successfully the low-altitude special-weapon-delivery maneuvers after approximately 10 operational flights. If two

flights per day of eight passes each are flown, the average pilot can qualify in a 5-day period. Pilots who train on an instrumented range learn to perform these maneuvers with such accuracy that they can fly them successfully on any target. On the other hand, pilots who train on an uninstrumented range learn by a hit-and-miss process of adjusting any one of the variables in a given maneuver in order to hit a particular target. If the variable adjusted is not the correct one, the pilots are unable to score hits on other targets.

Weapons training officers, who were questioned on the length of time required to train a pilot on an uninstrumented range as compared with an instrumented one, gave varied estimates. Some estimated that instrumented ranges reduce training time by a factor of four; others stated that a pilot can never be satisfactorily trained on an uninstrumented range. The tremendous savings in man hours and aircraft operating expense soon justifies the relatively small investment in training-range facilities.

Appendix A

POWER REQUIREMENTS FOR RANGE FACILITIES

The following requirements are for the instrumentation, including radar acquisition when commercial power is used. Utilities, and communication requirements will vary with each range and are not included in these calculation. Twenty-five of the 30 amperes in the second item are used to drive the motor generator set which supplies 400-hertz power to operate the radar.

115-volt	60-hertz	1-phase	...	25-amperes
208-volt	60-hertz	3-phase	4-wire	30-amperes
208-volt	400-hertz	3-phase	4-wire	25-amperes

Appendix B

RADAR TECHNICAL INFORMATION

The electronic characteristics of the radar are as follows:

Acquisition

Transmitter

Frequency, MHz	"S" band 3,100 to 3,500
Transmitter	Tunable magnetron
Peak RF power, kw	1,000
Pulse repetition frequency, pps	1,000
Pulse duration, μsec	1.3

Receiver

Antenna coupling	TR and ATR duplexing assembly
Receiver type	Double detection
Local oscillator	6BL6 reflex oscillator with plug-tuned external cavity
IF frequency, MHz	60
IF bandwidth, MHz	2.3 (3 db down)
Frequency control	AFC and servo tuning
Receiver noise figure, db	15

Tracking limits of operation

Azimuth	Continuous, rotates at 10, 20, or 30 rpm
Elevation	0 to 1,250 mil (70 deg)
Range, yd	120,000
Parallax, feet from van	300
Resolution	Can distinguish between aircraft targets separated by 200 yd in in range or 35 mil (2 deg) in azimuth

Power requirements

400-hertz 3-phase 208-volt 25-kw

Tracking

Transmitter	
Frequency, MHz	X-band, 8,500 to 9,600
Transmitter	Tunable magnetron
Peak RF power, kw	250
Pulse repetition, cps	1,000
Pulse duration, μsec	0.25
Receiver	
Antenna coupling	TR and ATR duplexing
Receiver type	Double detection
Local oscillator	2K45 reflex klystron
IF frequency, MHz	60
IF bandwidth, MHz	10
Frequency control	AFC
Receiver noise figure, db	12.5
Antenna	
Type	Metal-plate, phase advance lens
Beam, vertical	20 mil at 1/2 power point
Beam, horizontal	20 mil at 1/2 power point
Gain, db	39
Minor lobes, conical	Scan 26 db
Polarization	Vertical
Radar presentation	
Azimuth indicator	5 inches medium persistence "A" scan with lobing, range notch and expanded sweep
Elevation	Same
Range	Same except no lobing
Notch width, yd	100
Expanded sweep, yd	500
Sweep length, yd	Variable from 20,000 to 100,000
Tracking limits of operation	
Azimuth, mil	0 to 6,400 (no limit)
Elevation, mil	-180 to +1,600
Tracking rates	
Range, yd/sec	600
Azimuth, mil/sec	700
Elevation, mil/sec	500
Slew rate (range only), yd/sec	6,000
Resolution	Can distinguish between targets by 18 mil in azimuth or elevation, and 65 yd in range

Periscope
  Field of view, mil 100
  Magnification . . . . 8 power
  Reticle . . . . 5 mil divisions

Power requirements

400-hertz	3-phase	208-volt	5-kw
60-hertz	1-phase	110-volt	1-kw

The theory and operation of the M-33 radar tracking circuits is covered in detail in TM 9-6093-1.[1] The principal modification of the M-33 radar for use with the AN/FPS-102 system is in the computer and the plotting table. Figure 25 shows the fundamental relationships between the information received by the radar in the form of (a) polar coordinates and (b) the rectangular coordinates required by the plotting table.

The tracking radar continuously supplies information concerning the location of the aircraft. This information is in the form of D_o (slant range to the aircraft from the radar), E_o (angular elevation of the aircraft), and A_o (azimuth bearing). Figure 25 shows that this information is sufficient to locate the aircraft in space. The slant range D_o, the angular elevation of the target E_o, and the azimuth bearing of the target A_o, can now be considered known quantities. Polar data provided by the radar is converted to rectangular data by the computing amplifiers. This group is illustrated in Fig. 26 in block form. It consists of the range data potentiometer, the plus D_o network and amplifier, the minus D_o network and amplifier, the elevation data potentiometer, the plus R_o network and amplifier, the minus R_o network and amplifier, the quadrant switches, and the azimuth data potentiometer.

The brush arm of the range data potentiometer is driven by the range servo group (TM 9-6093-1, page 358, paragraph 148). The voltage at the brush is proportional to the slant range D_o, and has a scale factor of 0.0025 volt per foot. This voltage is applied to the plus D_o network and amplifier where the scale factor is changed from 0.0025 volt per foot to 0.001 volt per foot. The output of the plus D_o network and amplifier is minus D_o. It is applied to the minus D_o network and amplifier. The resultant output of the plus D_o and minus D_o amplifiers is sent to the elevation data potentiometer, the brush arm of which is driven by the tracking elevation servo group to an angle proportional to E_o (TM 9-6093-1, page 412, paragraph 169). One brush of the elevation data potentiometer continuously samples a voltage proportional to vertical height (elevation), H_o, and the other brush samples a voltage which is proportional to horizontal range, R_o. The H_o voltage is sent through the summing amplifiers to the plotting table (Fig. 17) where it is plotted by the right-hand pen as aircraft elevation above the flight line.

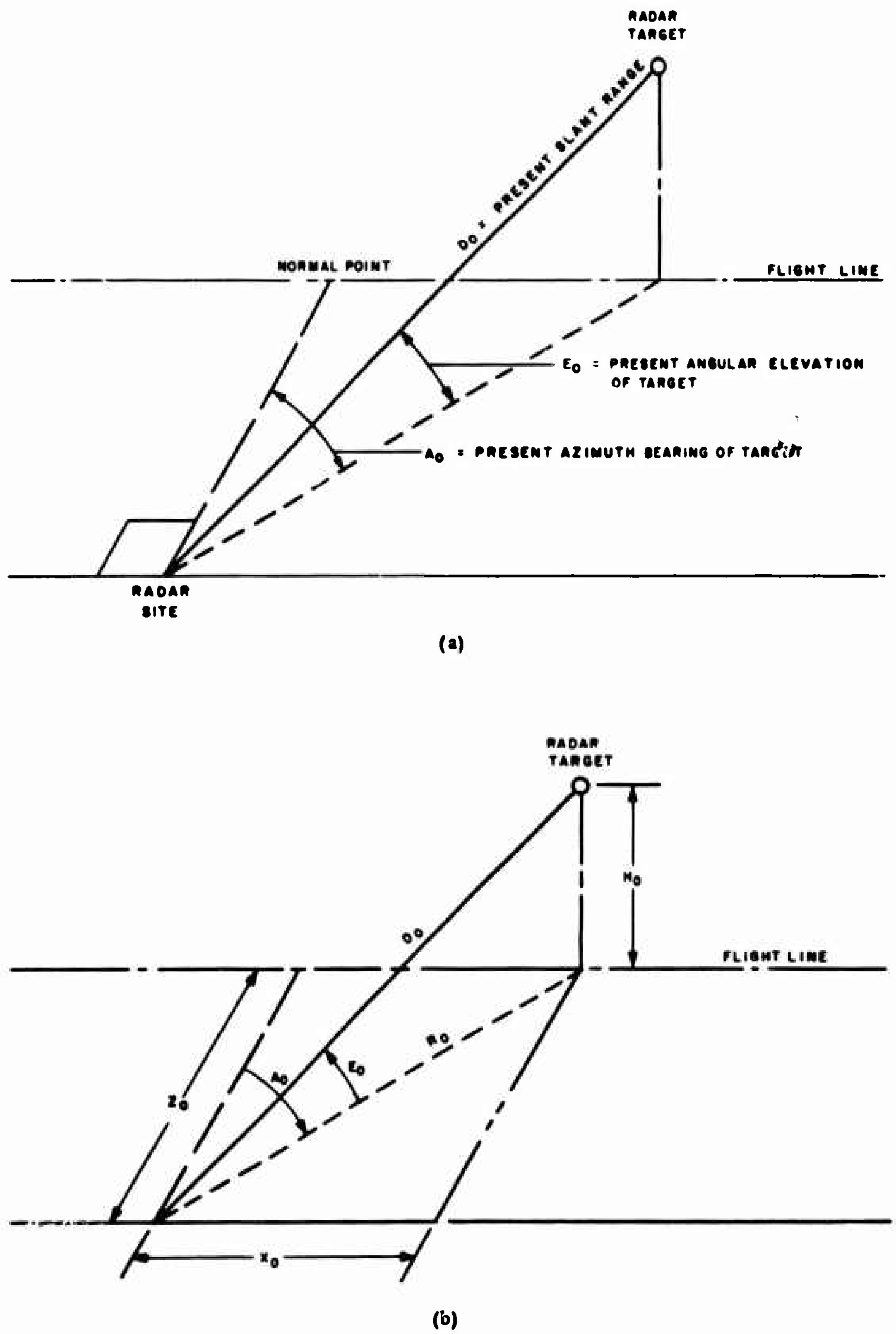

FIG. 25. Location of Radar Target.

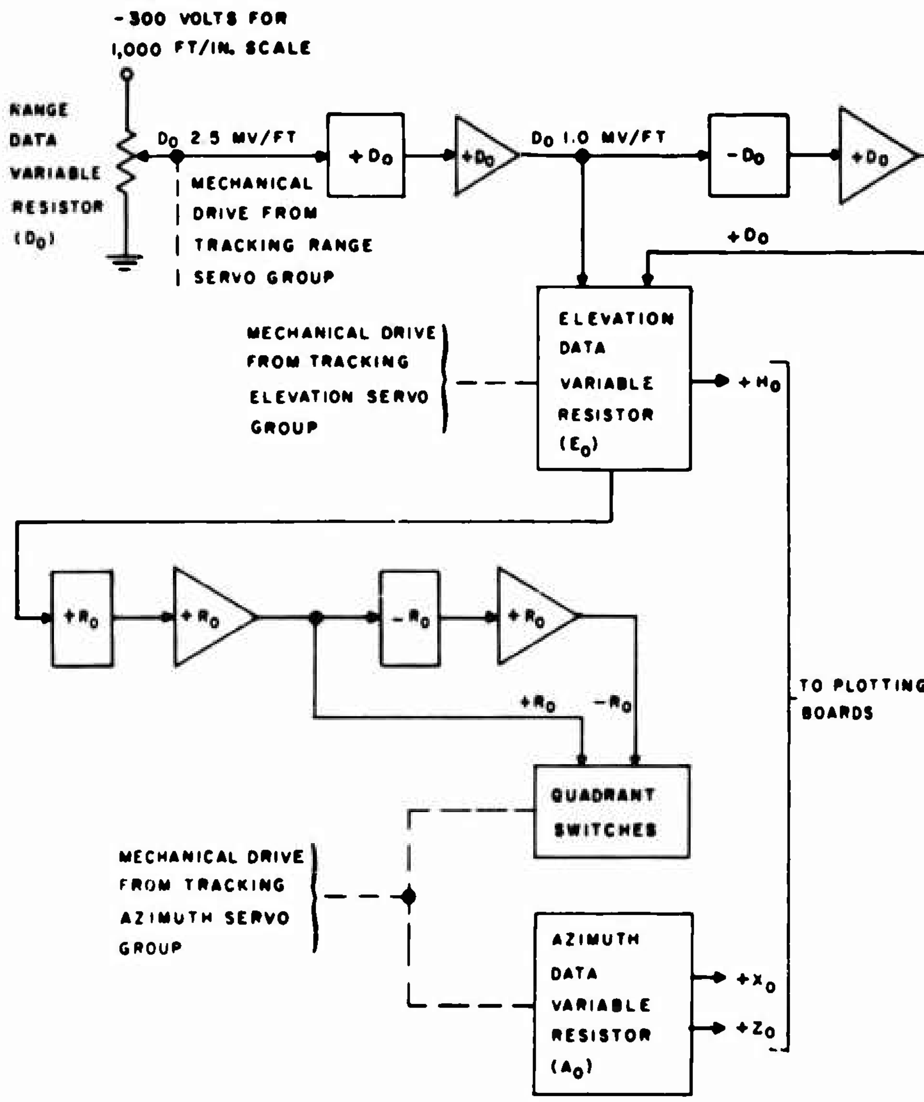

FIG. 26. Observed Aircraft Coordinates Group.

Equal and opposite voltages are needed for the determination of the other two Cartesian coordinates, X_o and Z_o, so R_o is applied to the R_o networks and amplifiers, similar to the D_o operation except that there is no scale factor change but a polarity change only. In this way, equal and opposite voltages are produced that are applied to the azimuth data potentiometer through the quadrant switches. The brush arm of the azimuth potentiometer is driven to an angle proportional to A_o by the azimuth servo group (TM 9-6093-1, page 388, paragraph 160). The voltage output at the brush arm of the potentiometer is proportional to the position of the aircraft along the aircraft line of flight with respect to the radar, X_o (R_o sin A_o) and the position normal to the aircraft line of flight, line Z_o (R_o cosine A_o). The correct polarity for these voltages is maintained by the automatic operation of the quadrant switches.

The range data potentiometer, a linear wire-wound resistor filled with oil, converts the slant range of the radar's target into a negative DC voltage D_O. The brush arm is driven by the tracking range servo group. When driven to the top of the potentiometer, the voltage at the brush is minus 300 volts, which represents a range of 120,000 feet. Since the potentiometer is linear, the voltage at the brush is 300 volts/120,000 feet or 0.0025 volt per foot in range. D_O from the range potentiometer is fed to the 120,000-foot transfer switch SI. At ranges above 120,000 feet, switch SI bypasses the potentiometer and 300 volts is applied to the D_O network continuously until the range is reduced below 120,000 feet and SI actuates and returns control to the potentiometer.

The D_O network and amplifier serves to isolate the range data potentiometer from the elevation data potentiometer and to convert the scale factor from 2.5 millivolts per foot to 1.0 millivolt per foot. This is necessary because the plotting board scale factor is set at 1,000 feet per inch or 1 volt per inch. An output of 1 millivolt for each 2.5 millivolts input is obtained by use of a 2.5-megohm input resistor and a 1-megohm feedback resistor around the amplifier. This follows the equation

$$\text{Output Voltage} = \frac{\text{Input Voltage times Feedback Resistor}}{\text{Input Resistor}}$$

The amplifier inverts the D_O voltage which is then applied to one side of the elevation data potentiometer and to the input network of amplifier No. 2 where it is again inverted and applied to the other side of the elevation potentiometer. Number 2 amplifier has unity gain and its function is to reverse the polarity of the D_O voltage.

The plus D_O and minus D_O voltages are applied to the elevation data potentiometer which is located in the elevation data converter of the tracking elevation drive. The brush arm of the potentiometer is mechanically coupled to the elevation drive and rotates in synchronism with the elevation of the tracking antenna. The data potentiometer has sine card E_O - 10 and a cosine card E_O - 9, each of which performs a separate function. D_O is applied to the sine card, the brush of which picks off a voltage proportional to E_O giving present vertical height. H_O is computed from the equation

$$D_O \text{ Sin } E_O = H_O$$

H_O is plotted by the right plotting pen as aircraft elevation. In the second function, minus D_O is applied to the cosine card and the brush picks off a voltage proportional to R_O (horizontal range). This is computed from $D_O \text{ Cos } E_O = R_O$. R_O voltage is applied to the horizontal range network and amplifier.

The brush arm displacement of the elevation data potentiometer is 2 E_O. This indicates that the ratio between arm of displacement and

antenna elevation is 2:1. The cards on which the potentiometer resistance is wound are so shaped that 180 degrees of mechanical movement of the brush represents 90 degrees of electrical movement. It should also be noted that portions of the resistor extend beyond the ground connections to a minus D_o connection, providing negative angles of elevation (angles of depression).

Since both polarities of R_o are needed and since they must come from a low impedance source, R_o from the elevation data resistor is applied to the plus R_o network and to an amplifier which reverses the voltage polarity to the minus R_o network and amplifier. The function of these amplifiers is to invert and isolate in the same manner as the plus D_o and minus D_o circuits. The plus R_o and minus R_o voltages are applied to the azimuth data resistor through the quadrant switches. The resistor and switches are located in the azimuth data converter of the tracking antenna. The plus R_o and minus R_o voltages are applied through the quadrant switches (TM 9-6093-1, page 505, paragraph 220) at proper angles of azimuth to ensure the correct polarity of X_o and Z_o throughout the 6,400 mils of azimuth displacement A_o.

The brushes of the azimuth data potentiometer are mounted on opposite ends of the same control arm and, therefore, displaced 180 degrees. Due to the shape of the resistor cards, however, this physical displacement represents only 90 degrees electrically. The brush displacement to antenna angle is therefore 2:1 as it is in the elevation data computer. Both brushes ride on cards and one taps off X_o (R_o Sin A_o) while the other taps off Z_o (R_o Cos $A_o = Z_o$).

The system accuracy is controlled by checking the plotting table scale factor. This is done by turning the radar antenna to 4,800 mils, 0-mil elevation, and setting 5,000 yards manually on the range computer dials. At these settings, the sine value of azimuth and the cosine value of elevation are each equal to one, and the output of the range computer to the X-axis of the plotting table is proportional only to range. Thus, the X-displacement of the plotting table arms can be adjusted to 1,000 feet per inch. If the antenna is now raised to 1,600 mils, the sine value of the elevation angle will be one and the Y_L (elevation) pen displacement can be checked. Since range data is processed through the same operational amplifiers, the horizontal range (Z-axis) can be checked by turning the antenna to 0 mil in azimuth and elevation and comparing the range dial reading in yards with the Y_R (range) pen displacement in inches at the 1,000-feet-per-inch scale factor. It should be noted that scale adjustments of either of the axes should be made by adjustment of their respective summing amplifier networks.

In practice, the azimuth and elevation drives are controlled by one operator and range by another. To pick up a target, the operators direct the antenna toward a point on the run-in line and set in the correct range on the range dials. As the target aircraft passes through the field of view of the optical system and the antenna, and into the range gate, the

operators track it by adjusting the aided tracking rates. When the radar is located 20,000 feet from the flight line, tracking rates for targets moving at 500 knots are 2.4 degrees per second in azimuth and 330 feet per second in range.

Appendix C
MODEL 5 TRACKER

The frame of the tracker (Fig. 14) is a 4- by 6-inch steel box column 81 inches high. The base is "T"-shaped, 40 by 30 inches, and is bolted to the deck after it is leveled with jack screws. The tracker seat, tracker platform, and control head for the hydraulic system that drives the plotter are supported by a 3-inch column welded to the tracker base. The seat and control head assembly are not power driven, but may be freely pivoted by the operator. Both seat and platform are adjustable in height for operator comfort in using the binoculars. An adjustable friction brake is used to prevent the control head support from turning too freely. The top of the tracker is in the shape of an inverted "L" with an arm 25 inches long that supports the dovetail block. This block contains two ball bearings and a shaft 1 inch in diameter by approximately 10 1/2 inches in length. This is the vertical axis and is the pivot point in the pantograph system which allows the tracker vector tube carrying the binoculars to pivot in the horizontal direction. The line-of-sight from the binoculars to the aircraft at the flight line is the long arm of a pantograph and the short arm is from the pivot point to the plotter vector block. The plotter scale is 1,000 feet to 1 inch. In order that the aircraft may fly a course sufficiently offset from the flight line to allow for wind effect on the projectile, the dovetail is calibrated in increments of 0.010 inch which is equivalent to 10 feet at the flight line. The adjustment can either shorten or lengthen the arms of the pantograph, allowing the aircraft to fly in a course parallel to the flight line but offset up to ±1,500 feet.

The vector tube is mounted in a clamp in a stirrup at the end of the vertical axis. The vector clamp has steel shafts at each side that fit ball bearings in the stirrup. The center line of these shafts is the horizontal axis that allows the tracker to pivot in elevation. Movement at the pivot point in nonaxial directions is held to ±0.003 inch. The horizontal axis is 62 inches above the finished flooring. Plotter accuracy is established at installation and therefore scale and calibrating adjustments are made at the time of installation. The operational length of the vector tube arm is established when the plotting and tracking units are bolted to the floor. The tracker is bolted in place with the pivot point directly over the point from which the orientation markers for the specific tracker were surveyed. It is leveled, then

adjusted (in relation to the plotting table) to an accuracy of ±0.015 inch which allows a maximum error of 30 feet over a flight line distance of 36,000 feet.

Since the telescoping vector arm is fastened between the tracker pivot point and the vector block of the plotter, it changes in length as the optical distance to the aircraft changes. In this way, the ratio between the length of the pantograph arms is maintained and the plot is accurate for all positions of the aircraft in the X-Y plane of the flight line.

The binoculars are mounted on the vector tube in front of the pivot point and offset 9 inches. This allows the vector tube to pass over the operator's shoulder and positions the operator so that he is able to turn and tilt his head with the binoculars. The tracker is connected to the plotter by the vector tube at the pivot point on the vertical cross-head block; this causes the plotter to drive the tracker. Since binoculars and vector tube are the sole load on the system, no difficulty is encountered with angles as great as ±80 degrees.

TRACKER CONTROL

The manual movement of the control head drives two balanced transistor power amplifiers which drive the twin hydraulic pumps (Fig. 27) that provide hydraulic pressure for operating the plotter. The operator starts the electric motor, which drives the hydraulic pumps, by pressing down spring-returned switches with the palm of either hand. Toggle switches are provided to open the circuit to prevent the operation of either the horizontal or the elevation drive pump if the operator wishes. When the control handles are in a neutral position, equal power is fed through the transistors, and the hydraulic pump's servo valve is held in the center position, holding the yoke on the variable-yoke hydraulic pumps in neutral so that hydraulic fluid is not pumped. Thus, even though an electric motor drives the hydraulic pumps, differential pressure is not generated and the hydraulic motors on the azimuth and elevation drives do not rotate. When the operator moves the position of the control handles in any direction from neutral, the amplifier signal is unbalanced, causing the servo valve to move the pump yoke off-center, and pressure is generated by the affected pump to drive its hydraulic motor. As the yoke on the pump passes through its central or neutral position, the rotation of the hydraulic motor passes through zero and is reversed. The small potentiometers shown on the control head are used to balance the outputs when the transistors are not perfectly matched.

Additional switches on the head are provided to control other functions. With his right thumb, the operator controls the limit-return switch that drives the plotter out of limits, and with his left forefinger, he operates the GSAP camera switch. The switch by the operator's left thumb is a spare for future modifications.

DRIVE SYSTEM

A 1-horsepower electric motor drives the twin variable-yoke hydraulic pumps (Fig. 27) through a gear train that operates in the following manner. The 40-tooth drive gear of the motor drives the 82-tooth gears of the hydraulic pumps; all gears are 32 pitch with a 20-degree pressure angle. Each of the pumps, both of which are located in the oil sump of a Vickers Type AA16865A hydraulic pump housing, has a maximum output of 0.260 cubic inch per revolution, or 1.92 gallons of hydraulic fluid per minute at 1,700 rpm. The two outputs of the pumps drive two Vickers Model MF-3171130-BC3 hydraulic motors that control the elevation and horizontal positions, respectively, on the plotter (Fig. 16). Each motor displaces 0.378 cubic inch per revolution and, at a speed of 1,173 rpm, requires 1.92 gallons of hydraulic fluid per minute to drive a lead screw through a 4:1 gear reduction at a maximum speed of 293 rpm. The horizontal screw has a lead of 0.437 inch per revolution. The lead screw, turning at 293 rpm, moves the crosshead block and pen on the plotter in the X-axis at a speed of 2.134 inches per second, which is equivalent to an aircraft flying along the flight line at 1,280 knots. The elevation screw has a lead of 0.413 inch per revolution and, when rotating at 293 rpm, moves the vector block and the pen on the plotter in the Y-axis at 2.017 inches per second, which is equivalent to an aircraft climbing at the rate of 1,210 knots. The range function of the plotter is entirely electrical and is taken from the M-33 plotter as a unit. A servo motor drives the range pen from signals supplied by the range computer. A feedback potentiometer geared to the servo motor supplies error signals to drive the range servo to a null. The pen block is driven by a steel cable wrapped around a pulley on the servo drive motor.

TRAVEL LIMITS OF PLOTTER

Since the equipment would sustain severe damage if the crosshead or vector blocks were driven into the end of the plotter table, two types of limit protection are provided. Microswitches are mounted about two inches from each end of travel in both horizontal and elevation positions (Fig. 16). If either the crosshead or vector block depresses one of these switches, an electrical circuit opens and stops both pumps and drive motors immediately. The operator then returns the controls to neutral, presses the limit-return switch, and turns the control to drive the block in the direction away from the limit switch. If the operator does not reverse the control when the limit-return switch is depressed, the block will continue through the limit switch and again be in a position to cause damage. To overcome this possibility, a friction-type clutch is mounted between the output of the elevation gear box and the lead screw drive. When the block comes against a stop, the clutch slips so that the hydraulic motor is disconnected from the lead screw. The operator must depress the limit-return switch again and reverse the control to drive the block out of limits. Although the friction clutch would disconnect the hydraulic drive in elevation if the limit switches

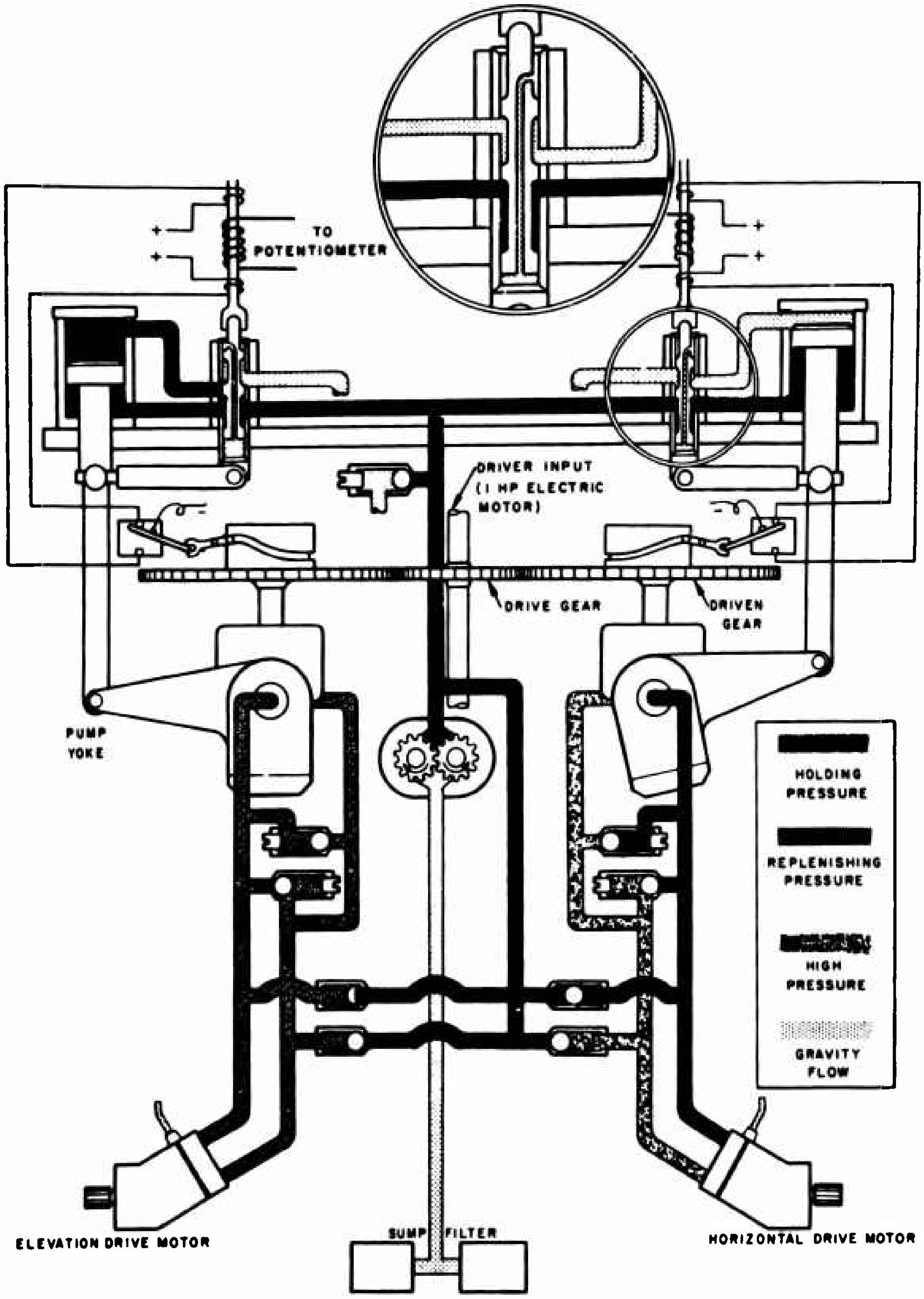

FIG. 27. Hydraulic System of Pumps.

were not in the circuit, the vector block may reach the clutch with sufficient speed to damage the plotter. The limit switches eliminate this potential hazard and also reduce wear on the clutch.

On the horizontal drive, the clutch is replaced by a bypass valve in the hydraulic pump to limit the pressure to 300 psi. A stop is placed on the lead screw, just beyond the limit switch, which prevents further travel; this causes the pressure to build up from its normal of 100 to 300 psi, and the bypass valve opens, preventing further build-up.

Appendix D

SKYSCREEN SYSTEM FOR MEASUREMENT OF AIRCRAFT SPEED

The telescope skyscreen system is advantageous in that it eliminates the need for electrical cables from the control building to the flight line, can make use of wasteland or water for flight line, and permits concentration of all except bomb impact-spotting equipment in one building.

Each telescope is of the Newtonian type, 6 inches in diameter by 48 inches long, and contains a photomultiplier tube and a spherical mirror with a 36-inch focal length. A Barlow lens with a focal length of 1.312 inches increases the focal length of the optical system without the size of the telescope having to be increased. By adjusting the Barlow lens from 5/16 to 9/16 inch inside the focal plane of the simple optical system, the focal length can be adjusted from 47 to 63 inches as compared to the 36-inch focal length of the original telescope. The telescope is 70 power. Use of the Barlow lens also makes the response curve flatter over a wider variation in ambient light.

The telescopes are aligned by boresighting through the optical system to the billboard markers along the flight line to the pole at target center. This is done by removing the photomultiplier tube and inserting an eyepiece in the aperture of the telescope. The eyepiece is set to focus in the same plane as the sensitive grid of the photomultiplier tube. When image size and focus are satisfactory, the telescope is adjusted to position the billboard in the center of the 20-foot-wide field of view, and the telescope is raised to cover elevations from 50 to 250 feet or from 50 to 450 feet above the flight line. The field of view is controlled by means of a mask placed 3/8 inch from the focal plane of the optical system. A slit, 1/32 by 3/8 inch, in this position restricts the field of view to 20 by 200 feet at a distance of 20,000 feet. This size slit is most commonly used; however, for night flying, a slit 1/32 by 3/4 inch, allowing a field 20 by 400 feet, is often used. After boresighting is completed, the telescope is clamped in position and the alignment is rechecked. The eyepiece is removed and the photomultiplier tube is replaced in position and connected to the amplifier.

Check or reference points, on a line-of-sight from the control building to at least three points on the flight line, must be used if the system is to be boresighted over water or inaccessible terrain. However, if water is in the field of view of the skyscreen, white caps of reflections in the water will trigger the telescopes. In such a case, the auxiliary tracker speed-switch system, as described in this report, should be used.

BIBLIOGRAPHY

U.S. Naval Ordnance Test Station. Model 5 Tracker and Profile Plotter, Skyscreen Telescopes, and Associated Electrical Equipment. Description, Operation, and Maintenance. (A Preliminary Manual). China Lake, Calif., NOTS, February 1964. (NOTS TP 3330.)

———. Aircraft Ranges for Training Pilots in Special-Weapon-Delivery Techniques, by Everett B. Hill. China Lake, Calif., NOTS, June 1964. (NavWeps Report 8414, NOTS TP 3346.)

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13. ABSTRACT

This report describes in detail the instrumentation necessary for training aircraft pilots in bombing techniques. The essential elements of the system are a modified M-33 radar, two Model 5 optical trackers, two Model 5 flight-profile plotters, six skyscreens, three impact-spotting quadrants, one impact-spotting board, and a timing console. When the training includes dive bombing and conventional-weapons delivery, optical acquisition and radar acquisition systems are added. This equipment measures the aircraft's speed and flight path while it performs these maneuvers.

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Bombing Training Ranges						
Radar Control Plotter						
Three-Dimensional Plotting						

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